ECONOMIC DIFFERENTIATION IN HONGSHAN CORE ZONE COMMUNITIES (NORTHEASTERN CHINA): A GEOCHEMICAL PERSPECTIVE

by

Tao Li

B. S., Northwest University (China), 2004

M. A., University of Science and Technology of China (China), 2007

D. Sc., University of Chinese Academy of Sciences (China), 2010

Submitted to the Graduate Faculty of

The Kenneth P. Dietrich School of Arts and Sciences

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh
2016

UNIVERSITY OF PITTSBURGH

KENNETH P. DIETRICH SCHOOL OF ARTS AND SCIENCES

This dissertation was presented

by

Tao Li

It was defended on

February 29th, 2016

and approved by

Bryan K. Hanks, PhD, Associate Professor, Anthropology

Katheryn M. Linduff, PhD, Professor, History of Art and Architecture

Loukas W. Barton, PhD, Assistant Professor, Anthropology

Chair & Dissertation Advisor:

Robert D. Drennan, PhD, Distinguished Professor, Anthropology

Copyright © by Tao Li

2016

Economic Differentiation in Hongshan Core Zone Communities (Northeastern China): A Geochemical Perspective

Tao Li, PhD

University of Pittsburgh, 2016

Region-wide, systematic investigations were carried out in the Hongshan periphery and core zone to investigate how the earliest chiefly polities in northeastern China came into being. Possible causal factors, such as high levels of regional populations and intra-community conflict, were rejected by those regional survey projects. Economic or productive differentiation as an alternative and plausible explanation was proposed in this research background to explain the greater and more impressive material culture in the Hongshan core zone. Seeing pottery networks as a most direct indicator for economic interdependence between households, a geochemical study was carried out on 715 sherds selected from 16 Hongshan households in three residential areas (Sanjia, Dongshanzui, and Erbuchi) in the core zone. The geochemical study was complemented by a mineralogical investigation on a smaller sample from the same sherd pool.

The results suggested that pottery-making was organized in different residential areas using local raw materials; non-utilitarian vessels were clearly produced with more labor investment and probably a low level of specialization, but they were no different from utilitarian ones in terms of procurement sources of pottery raw materials. Altogether, an ordinary Neolithic village economy is indicated for Hongshan core zone communities.

The pottery distribution patterns suggested a wide and open pottery network crossing different neighborhoods, residential areas, and political entities. Economic connections were clearly established between Hongshan households from a few nearby districts, and the transfer of pottery created a chain of interaction that connected one end of the Hongshan zone to the other indirectly and facilitated cultural sharing of styles and other behaviors that helped create the Hongshan culture. In each residential area, a very few households stood out against others for their higher household status, and they all demonstrated a much stronger economic tie with fewer pottery producers. Yet, considering that higher-status households did not have exclusive access to certain pottery producers and nor did they rely strongly on the same producers, control over production and distribution of pottery seems not likely to be the only (or even a major) strategy that some Hongshan individuals or households employed to achieve their eliteness or power.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

First of all, I would like to express my sincerest appreciation to Professor Robert D. Drennan, my dissertation advisor and a great mentor. Throughout my entire PhD life at Pitt, Professor Drennan has always been supportive, caring, and ready for discussion, advice, and help. The weekly meetings and informal communication (emails, short conversations during trips and on dining tables, etc.) between Professor Drennan and I have allowed me to make consistent progress on (and finally be able to finish) my PhD dissertation. I would also like to thank my other committee members—Professors Bryan K. Hanks (Anthropology), Katheryn M. Linduff (History of Art and Architecture), and Loukas W. Barton (Anthropology)—for their keen observations on the weakness in some of my arguments and constructive suggestions on how to improve the coherence and clarity of my statements.

Dr. Christian E. Peterson (Department of Anthropology, University of Hawaii at Manoa) made a big contribution to my PhD project at the Niuheliang Workstation in western Liaoning. Without his help in ceramic identification and fruitful discussions, the sample size would be a lot smaller and the stratified sampling of Hongshan core zone sherds would not have been done within a few weeks. I want to thank Dr. LUO Wugan (University of Chinese Academy of Sciences) for his patience and good suggestions while I had trouble with the pXRF analysis. Professor LU Xueming (Renmin University of China) and Mr. ZHU Da, director of the Niuheliang Workstation, answered my questions on Hongshan material culture, and took good care of us (food and accommodation) during our stay at the Niuheliang Workstation. Professor WANG Changsui, my former advisor, and Dr. ZHU Jian (both from University of Chinese Academy of Sciences) shared important ideas about sourcing pottery geochemically since the beginning of my PhD project. Dr. ZHU Jian and his students prepared a small sample of Hongshan sherds and carried out the ICP-AES and benchtop XRF analyses, the results of which later helped me make the final decision on which methodology I would like to apply to the 715 Hongshan sherds.

I would like to give special thanks to my fellow graduate students at Pitt: James Williams, Camilla Kelsoe, Pedro María Argüello García, Julia Clark, Adam Berrey, Sebastian Fajardo, Francisco Garrido, Hugo Ikehara, LI Dongdong, Ng Chuen Yan, CHEN Peiyu, WANG Wenjing, CAI Yan, ZHAO Chao, QIU Yijia, ZHANG Chi, and RAN Weiyu. I would also like to thank the Chinese visiting students at Pitt's departments of Anthropology and History of Art and Architecture (BI Jingwei, HONG Meng, SONG Haichao, LI Moran, LIU Yuanqing, FAN Xiaopan, and HAO Yuanlin) and my landlord, roommates, and friends (Ms. Kathy BAI; LIU Gangqiang, HE Qixin, XU Yi, YANG Wang, ZHAO Heng, WEI Yanjun, GUO Chuanyu, and WANG Xiangnyu) for their kindness, understanding, and support.

Finally, I would like to thank my family. My parents have always respected and supported every decision I have made. My sisters and their in-laws have been taken good care of my mother while she is fighting against cancer. My little nephew, Pipi, has been the cutest bundle of joy. My face would always lighten when watching the video of his swimming with a swim ring at one month of age. Their unconditional love and care helped me go through difficult times. Without them, I would not have gone this far.

Completion of this dissertation would not have been possible without financial support from the National Science Foundation's Doctoral Dissertation Improvement Grant (NSF DDIG, grant no.: BCS1444978).

1. INTRODUCTION

1.1 Hongshan societies in northeastern China

During Hongshan times (4500–3000 BCE), fairly dramatic sociopolitical and economic changes took place in northeastern China (western Liaoning and eastern Inner Mongolia in particular). Decades of progressive archaeological excavations in this very broad region have revealed Hongshan public architecture (platforms thought to be used as temples and altars) and burials often associated with elaborate offerings (jade finely carved with supernatural themes). Both the public architecture and burials are quite impressive compared to contemporaneous late Neolithic remains elsewhere (e.g., Yangshao and Dawenkou sites in the Yellow River valley), and had made Hongshan remains stand out as special and unique in prehistoric China (Nelson 2003:13-14).

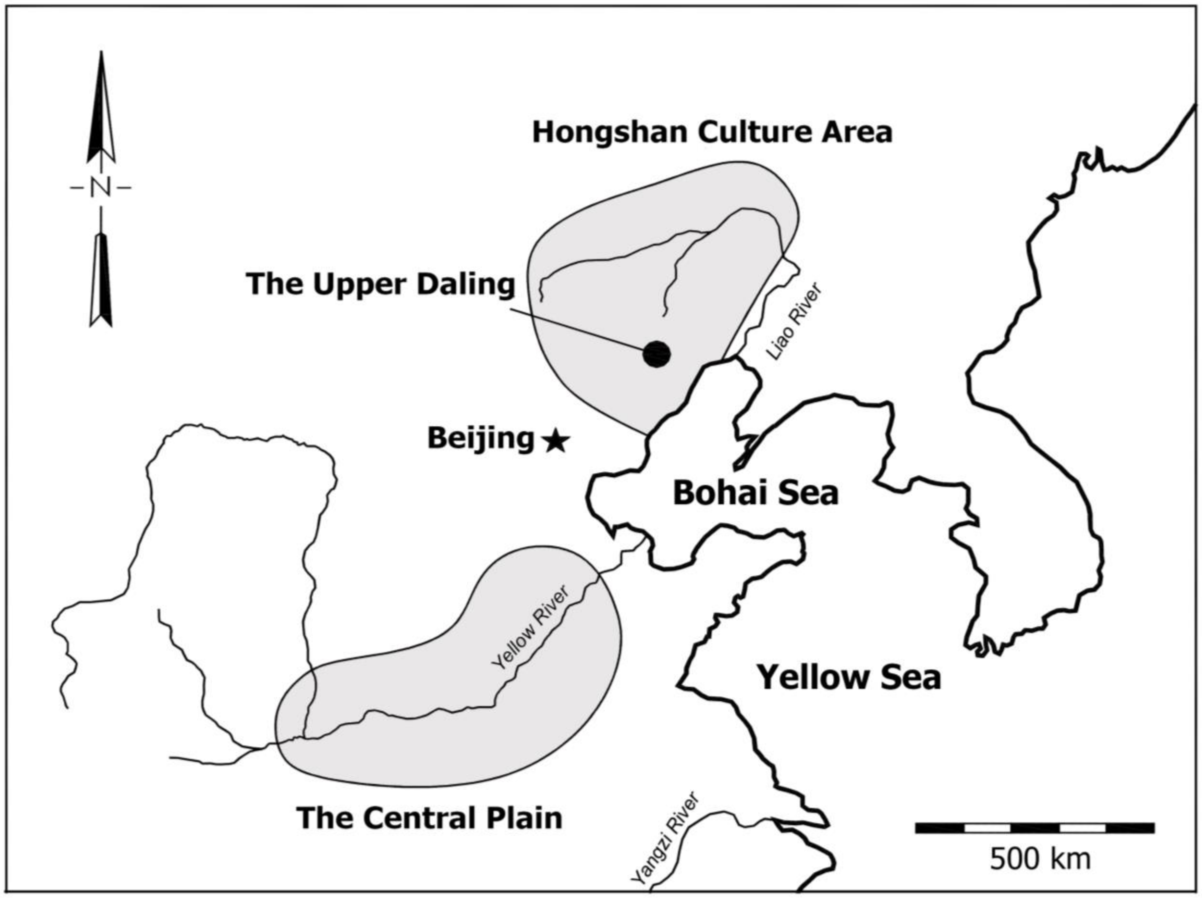

Figure 1.1: The Hongshan culture area and the upper Daling region (Peterson *et al.* 2014:3)

In addition to site-focused surveys and excavations, regional-scale data, on the other hand, have more fully documented shifts and changes that occurred in sociopolitical and economic organization of Hongshan societies. Two such datasets were obtained by full-coverage, systematic regional surveys conducted in the Chifeng region of eastern Inner Mongolia and the upper Daling River valley in western Liaoning (Chifeng 2011; Peterson *et al.* 2014). (See Figure 1.1 for the rough spatial limits of Hongshan culture area and location of the upper Daling region in northeastern China). They have revealed some most remarkable sociopolitical and economic changes that occurred in Hongshan times. For example, widely scattered small Neolithic villages and farmsteads gave way to clusters of local communities which were centered on a few larger central places; increasing reliance on agriculture became evident in subsistence economy; population levels grew faster both locally and regionally; and most importantly, the earliest supra-local communities (or districts) known for northeastern China were formed (Peterson *et al.* 2010).

Impressed by the wide distribution of shared Hongshan material culture and ideology, some researchers have argued, explicitly or implicitly, that the entire Hongshan occupation distribution must indicate a single powerful polity (e.g., GUO Dashun 郭大順 1995, 2007, 2008; GUO Zhizhong 郭志忠 2009; PENG Bangben 彭邦本 1990; SU Bingqi 蘇秉琦 1986, 1988; SUN Shoudao 孫守道 and GUO Dashun 郭大順 1984; WANG Huide 王惠德 1989). However, regional-scale data from Chifeng, the upper Daling River valley, the lower Bang River valley, and Aohan Banner suggest political integration only on a much smaller scale. Each of these regional survey projects have identified a great many small Hongshan polities and found no sign of larger or more central districts that dominated others. Therefore, overall sociopolitical integration or centralization of the entire Hongshan culture area was not supported. It is suggested for the reasons described above that these small Hongshan polities can be loosely referred to as chiefdoms (Drennan and Peterson 2006; Peterson 2006). Many scholars (e.g., Peterson and LU Xueming 呂學明 2013) have seen the individuals buried under platforms with symbolically carved jades as important Hongshan ritual specialists, and since each small district or chiefly polity appears to have such ritual facilities at its center, Hongshan political organization has been seen as relying relatively heavily on religious authority (Drennan and Peterson 2006).

1.2 Hongshan core zone and periphery

Regional-scale data obtained from the upper Daling River valley of western Liaoning and the Chifeng region of eastern Inner Mongolia have suggested a great many small Hongshan polities both in the core zone (核心區) and the periphery (周邊區). The distinction between the core zone and the periphery was made based on the varying densities and elaborateness of recognizable surface Hongshan public architecture remains (Peterson 2006:23). It was neither strictly nor neatly defined, but advanced to facilitate characterization of variation in amounts and scale of public architecture across the Hongshan area for comparative purposes. The distinction implies nothing at all about economic relationships of a world system between core and periphery, but simply distinguishes a core zone where evidence of Hongshan public architecture and burial ritual is especially abundant and elaborate, surrounded by a zone where the same sorts of remains occur in lesser amounts and on a less impressive scale. Figure 1.2 shows the separation of the core zone and the periphery.

The core zone, which is centered in present-day western Liaoning, includes the excavated sites of Niuheliang (牛河梁), Dongshanzui (東山嘴) and Hutougou (胡頭溝). The upper Daling survey region, within the core zone, has at least one Hongshan public building for every 15 km^2 [a recent 42.5-km^2 survey project around the Niuheliang site reports one Hongshan public architecture for about every 2 km^2 (Liaoning and

Renmin University of China 2015)]. By contrast, the Chifeng region in the periphery has less than one Hongshan platform, in a less elaborate and impressive form, for every 176 km^2 (Peterson and LU Xueming 呂學明 2013; Peterson et al. 2010).

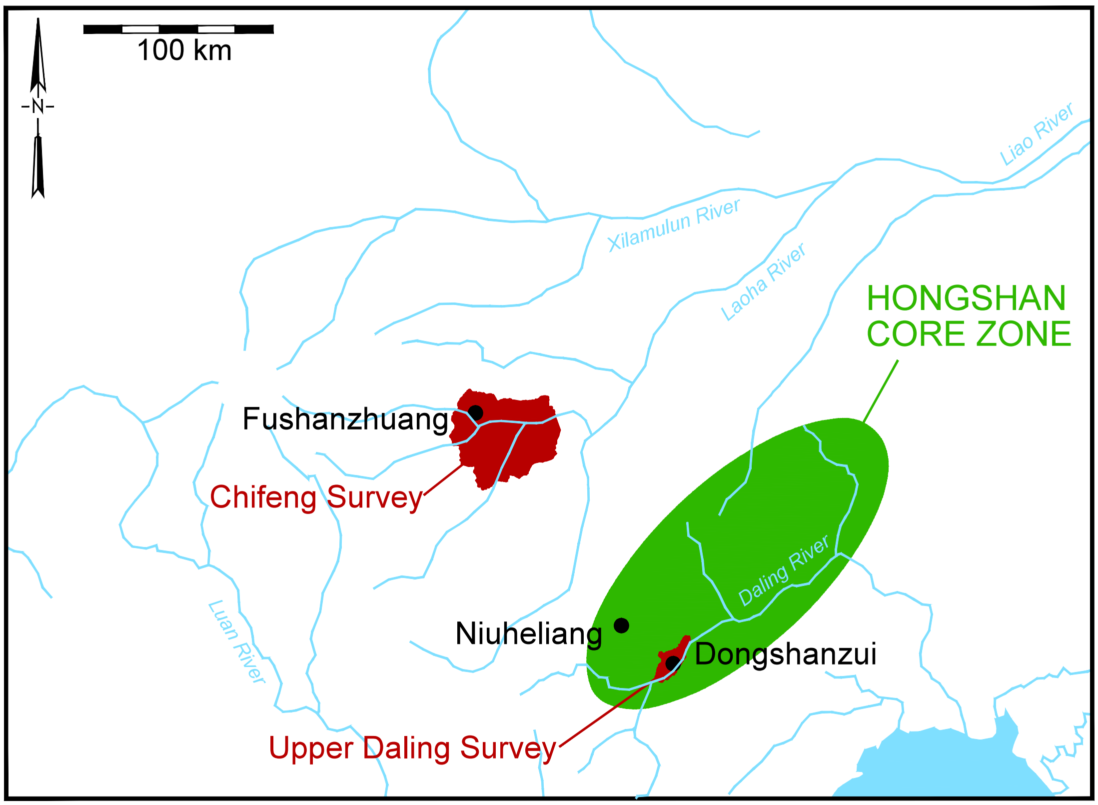

Figure 1.2: The Hongshan core zone and the periphery (Drennan *et al.* In press)

The most conspicuous and elaborate Hongshan archaeological remains, then, are concentrated in the core zone, leading scholars to consider this part of the Hongshan area, in some sense, the maximal expression of Hongshan archaeological culture. This provides an opportunity to delve into Hongshan social dynamics by investigating the factors that produced such a more elaborate but spatially restricted manifestation of cultural patterns across a much larger area.

1.3 Causes for the core zone's greater expression of material culture

The regional-scale data have confirmed the greater abundance and elaboration of Hongshan public architecture and funerary ritual in the core zone. How, then, did the Hongshan core zone societies produce such a sociopolitical integration? One possible answer to this question is that the Hongshan core zone communities might have made such an achievement on a substantially larger demographic scale, which allowed correspondingly more powerful leaders to mobilize public works labor from larger populations.

The upper Daling regional settlement study (e.g., LU Xueming 呂學明 *et al.* 2010) has pursued this possibility by estimating regional population levels of the Hongshan and other periods in the surveyed area. It was estimated that 750 to 1500 persons lived in 134 communities across the surveyed area (200 km^2) during the Hongshan period. This population density (4–8 persons/km^2) is only slightly higher than 2–4 persons/km^2 estimated for the Chifeng region well outside the core zone. The separation of settlement clusters that represented districts, their roughly similar populations, and the presence in each of apparently similar facilities for public ritual altogether suggest that none of them (the Hongshan districts) had become a powerful polity dominating others (at least in this part of the core zone).

In addition to the similar population levels, communities of the Hongshan period in the core zone and the periphery show substantial similarities in other aspects as well, including: locating sites for occupation; utilizing natural resources (e.g., agricultural and pasture lands, wild edible plants and animals); performing rituals and ceremonies; and organizing regional population into individual polities of relatively small spatial and demographic scale. It is evident that regional population densities in both the core zone and the periphery are far lower than would exert any pressure on subsistence resources, and that there is no evidence suggesting inter-community conflict in either the core zone or the periphery.

To summarize, what differentiates Hongshan communities in the core zone and the periphery seems to remain in the scale of and amount of labor and time spent in constructing public architecture related to ritual and ceremonial activities. This leads us to think of <u>another possible way</u> to account for greater monumental and ceremonial activity in the core zone: <u>greater economic (or productive) differentiation</u>.

One simple, obvious reason to connect the symbolic and spiritual life of Hongshan villagers to economics is that the construction of ritual facilities requires an economic investment in the form of labor mobilized to carry out these public works. A greater degree of differentiation between households in Hongshan villages with regard to productive activities implies a stronger economic interdependence between households and a more complex economy, which possibly provided Hongshan leaders (or elites) with enhanced opportunities to mobilize labor toward such ends.

Analysis of household artifact assemblages within Fushanzhuang, a Hongshan village in the Chifeng region in the Hongshan periphery, has indicated some very modest productive differentiation shown especially in lithic artifacts (Peterson 2006). If the core zone showed stronger evidence of productive differentiation and thus a more complex village economy represented by much stronger household interdependence, this might help us to understand how the greater investment in public ritual spaces came to be and, most importantly, how Hongshan elites might achieved their eliteness or power.

1.4 Economic differentiation in Hongshan core zone communities

The term economic differentiation (sometimes also known as productive differentiation), as we use it here, refers to differences between households within a local community in the balance of activities involved in producing subsistence and non-subsistence goods of various kinds that were widely utilized in daily life by ordinary people. To maintain consistency in writing, the term economic differentiation would be used throughout the whole dissertation.

The term economic differentiation was chosen in preference to craft specialization because we do not wish to imply full-time (or even part-time) specialists working in dedicated workshops to produce a considerable volume of goods; because we do not wish to exclude the production of subsistence goods; and because our focus here is not on the elaborate luxury or prestige goods upon which archaeological attention to craft specialization (including for Hongshan societies) has often focused. Despite the widespread use of the term craft specialization in the archaeological literature, there is considerable discussion about its proper definition and about the archaeological indicators of its various forms and modes. Underhill (1996) has reviewed some of the problems that can result.

In particular, among Hongshan archaeological materials, many discussions have been based on the finely carved jade and bottomless ceramic cylinders with elaborate painted decoration — Tongxingqi (筒形器). These are non-utilitarian goods of great significance in ritual and ceremonial activities and products of a level of skill that a number of researchers have argued can only be achieved by craft specialists (e.g., LU Xueming 呂學明 and ZHU Da 朱達 2008:73; TENG Haijian 騰海建 2009; XU Zifeng 徐子峰 2004). However, it is worth pointing out that, even though a possibly greater degree of economic differentiation could finally be indicated for the Hongshan core zone, it would probably still fall near the bottom of the scale of specialization usually investigated by archaeologists. More importantly, the existence of specialized craftsmen producing ritual goods does not necessarily mean that the provisioning of daily life in Hongshan villages involved very much economic differentiation or economic interactions between households. It is this latter aspect of the economy that this dissertation project seeks to investigate.

1.5 Research questions to be investigated in this dissertation

Pottery is an early human invention, and it has substantially changed the way humans lived (especially how they prepared, cooked, and stored food) since its invention. Even after pottery is broken into pieces and discarded as garbage, it can still survive, either on the surface or below the surface, for quite a long time due to its durable physical properties. For these reasons, pottery has been a central focus for archaeological interpretation and reconstruction of human behavior in the past (e.g., Tite 1999, 2008).

A distinction is frequently made between (1) luxury or ceremonial pottery for ritual, funerary, display and other uses, and (2) utilitarian pottery for the common activities of everyday life, including cooking, storage, and transport (e.g., Rice 1987). Production of the former may require a greater amount of time, labor, and specialized knowledge, and is often argued to be carried out only by very skilled and experienced craft specialists. The technical requirements for making utilitarian pottery may be relatively simple(r), and basic functional pottery vessels could be made virtually by every household or family group for its use from rudimentary materials widely available in almost any landscape.

The same logic holds true for Hongshan material culture. Although finely worked jade and elaborately painted pottery cylinders (Tongxingqi) are much-admired Hongshan artifacts, more than 60 years of field surveys and excavations have revealed perhaps 300 Hongshan jade carvings, quite a small quantity and low density considering that the Hongshan period lasted 1500 years and that Hongshan material culture is distributed across an area of some 250,000 km^2. Tongxingqi were found in larger quantities at more Hongshan sites, but the number is still quite small compared with the abundance of Hongshan utilitarian pottery sherds. It is the millions of sherds of utilitarian vessels that constitute the vast majority of surviving Hongshan material culture.

Thus, it is utilitarian pottery that this dissertation aims to use as a window into the economic organization of daily life for ordinary people in Hongshan villages. Five specific but interrelated research questions have been formulated in the hope of promoting our current understanding or generating new understanding of: (1) pottery production, distribution, and consumption in Hongshan core zone communities, (2) the varying degrees of access (or reliance) that households in the Hongshan core zone had to (or on) different pottery raw materials and pottery providers, and (3) the possible correlation between pottery procurement sources and differentiation in social or economic status among households in the Hongshan core zone. As non-utilitarian Hongshan vessels (Tongxingqi) would be included in the sampling, we could also investigate from a raw material procurement perspective how 'specialized' the production of non-utilitarian vessels would look like, compared to that noticed for utilitarian vessels. Finally, with all the proper interpretations of results obtained for each research question, we would be able to generate a picture of how residents of Hongshan core zone communities might have organized their everyday economic lives, which would advance our conception of what role and to what degree did economic differentiation play in the formation of social complexity in Hongshan societies.

1.5.1 Research Question 1

> *How much economic differentiation characterized Hongshan pottery making? Does it seem that most households made pottery vessels for their own daily use? Or, at the opposite extreme, was most of the utilitarian pottery made by only a few pottery producers?*

Pottery, no matter how it was produced and used to serve what purposes, is often a product of long-term social, cultural, and technological choices by a particular population. Thus, the way pottery was produced, distributed, and consumed in a particular prehistoric society at a particular region and time contains important clues regarding the pottery consumers' thoughts and behaviors in their everyday sociopolitical and economic lives. This in return offers a chance for us to understand how possibly the prehistoric villagers (such as the occupants of Hongshan core zone communities) organized themselves routinely, which can be very important for understanding local or regional social dynamics. The production of pottery during

Hongshan times, as was suggested in section 1.4, was almost certainly not be carried out on a scale and at a level that match well with what many scholars focusing on craft production would term "craft specialization". However, signs of economic differentiation have been noticed in the Hongshan periphery (Chifeng region) and there are some good reasons to lead us to believe that a greater degree of economic differentiation may characterize the economic lives of Hongshan core zone communities.

Understanding pottery production, distribution, and consumption in the Hongshan core zone through a geochemical analysis of carefully selected sherds is therefore a good way to reveal economic interdependence between households. On one end, if each household produced pottery for their own use, the economic communications between households (as evidenced by the consumption of pottery made from different procuremnt sources at each household) would be rare (or at least, very weak), then, households in the Hongshan core zone should be quite likely self-sufficient and the intra-household interdependence be very mild.

On the other extreme end, if all pottery (whether fine-paste or coarse-paste, utilitarian or non-utilitarian) consumed at most (if not all) of the Hongshan core zone communities shows very strong geochemical homogeneity indicating common production source units, a high level of intra-household economic interdependence would be indicated. (To be brief, a production source unit corresponds to a delineated compostional group, which is believed to very likely result from a specific pottery-making tradition maintained by a group of people, some particular processing recipes, or sometimes both. It is for this particular reason that we argued that a compositional group could represent a production source unit or a possible pottery producer. A detailed discussion of what the term "production source unit" means will be presented in section 2.3.4.)

1.5.2 Research Question 2

If most households did not make their own pottery, did they tend to acquire it from a single producer? Or from several producers?

From a materials science perspective, all pottery raw materials were prepared from clays and inclusions (whether naturally occurring or intentionally added), which were then shaped, formed, and fired by the potters to achieve some formal and functional characteristics. Therefore, geochemical compositions of the final pottery vessels reflect the <u>source</u> information of where pottery raw materials may have been procured and the technological traits of how pottery producers prepared raw materials to ensure that the consumers' requirements would be met. The <u>source</u> information about pottery not only refers to the geographical locations of raw materials exploited and utilized to make that pottery, but also to the potential number of <u>production source units (PSUs)</u> involved in pottery production. This latter aspect is a very interesting topic to investigate as it helps illustrate the local or regional provision of raw materials.

To be more specific, if a highly homogenous geochemical composition is not noticed for the investigated Hongshan core zone pottery, and instead, pottery consumed in each Hongshan core zone household shows a fairly large geochemical variability, it may suggest that inhabitants of each household have had access to different production source units and thus indicate the presence of more than one single pottery producer (or production source unit) in the Hongshan core zone. Different producers or production source units can be recognized or identified conceptually by looking for distinctive compositional groups that are delineated by featured geochemical compositions of investigated pottery. It is called a "conceptual" designation of pottery production source units because with the surface materials from the upper Daling survey project we could only perceive the presence of different resources provisioned by different production sources units but would have no clue where exactly they came from or who had mobilized or prepared them.

1.5.3 Research Question 3

> *If households tended to acquire all or most of their pottery from a single producer, did this correspond to zonation within settlements? That is, did all households in a particular neighborhood rely largely on a single procurement source? Or were households utilizing different producers intermingled spatially within settlements?*

The upper Daling survey project identified a total of 50 Hongshan households in three separated residential areas: Sanjia (三家),

Dongshanzui（東山嘴）, and Erbuchi（二布尺）. (More details about identification of the 50 Hongshan households will be introduced in section 2.1.2). It is these 50 Hongshan households from the three areas that constructed the sherd pool from which a sampling would be selected and studied in this dissertation. Research Question 3 was designed to explore whether or not one single producer had produced potttery for all the 50 Hongshan households. Answers to Research Question 3 relied closely on the delineation of compositional groups or production source units done to answer Research Question 2. If a very limited number of compositional groups (or PSUs) are identified, all (or nearly all) of which are clearly represented at each of the 50 households, it would lead us to believe that pottery production might have been carried out by a very few groups of people who dedicated themselves to pottery making and made a living through pottery exchange or trade with their near or distant neighbors who put a lot more efforts into doing other kinds of productive activities (such as farming).

If, in the other scenario, a lot more compositional groups or PSUs are strongly suggested for the three residential areas, as evidenced by groupings of pottery on the basis of their geochemical similarities, and if different areas show a focus on different kinds or combinations of PSUs, then the "one single producer (and maybe regional production center)" hypothesis is rejected. It would look more likely that pottery production took place in multiple locations using locally procured raw materials.

1.5.4 Research Question 4

> *If households tended to acquire pottery from multiple sources, did the proportions in which these sources were represented vary substantially from one household to the next? Or were the proportions of different sources quite similar across households within a settlement area?*

If Research Question 3 is answered negatively (that is, if multiple production source units are suggested for the three residential areas), it will be very interesting to know how similarly or differently inhabitants of two households in their everyday life consumed pottery made by different production source units. Intra-household variation in communicating with different production source units and consuming pottery made by different PSUs can be an indication of household interdependence and a source of differentiation in household status.

More specifically, the ability to access a certain number of pottery producers and to make such economic connection strong and stable could have been an important factor that helped some Hongshan individuals or households achieve economic superiority and therefore higher status. Research Question 4 aims to investigate such intra-household variations by making estimates of the proportions of different PSUs represented at the 16 selected households and then comparing them for patterns (if any). The difference observed during such comparisons, whether it is statistically significant or not, would lead us to formulate hypotheses to interpret the correlation between pottery procurement and household status.

1.5.5 Research Question 5

> *To what extent did utilitarian pottery distribution cross the boundaries between the supra-local communities or districts delineated in the regional settlement analysis?*

This last research question aims to understand communications beyond the local neighborhoods and asks whether or not (and/or how strongly) people living in two separate supra-local Hongshan communities could have interacted with each other economically. The delineation of supra-local communities has been done in regional settlement analysis by the upper Daling survey project, which assigned Sanjia and Dongshanzui to one supra-local community while Erbuchi to the other. With a fairly good number of samples selected from households in three different residential areas that belonged to two supra-local communities, we will be able to find out how each household was involved in the regional pottery networks and especially how pottery was distributed between supra-local communities. If the distribution of pottery was quite wide across the landscape and had crossed the geographical limits of supra-local communities, more active economic interactions between these supra-local communities would be indicated. A wide pottery distribution network would also help us understand the formation of shared Hongshan material culture in the core zone and beyond.

1.5.6 Additional Research Questions

In addition to the five main research questions described above, a large sampling of sherds would also make some other interesting topics (although less related to the main focus of this dissertation) potentially discussable. Two such topics seem most relevant and can be organized into additional research questions.

First, as a result of the stratified sampling strategy (see more details in section **2.4**), the sherd samples consist mainly of utilitarian vessel sherds but also of some non-utilitarian ones. This offers an opportunity to compare the geochemical variability of utilitarian vessels with that of non-utilitarian ones. Hongshan non-utilitarian vessels (Tongxingqi) have been long believed to be products of highly specialized production activities due to their finer texture, much larger shape and form, and more decorations (e.g., LU Xueming 吕學明 and ZHU Da 朱達 2008:73; TENG Haijian 騰海建 2009; XU Zifeng 徐子峰 2004). A geochemical understanding about procurement sources of both utilitarian and non-utilitarian vessels would advance our knowledge of pottery craft specialization in the Hongshan period and especially within this part of Hongshan core zone. For example, if Tongxingqi vessels seem to be produced from raw materials or by production source units very different from those indicated for utilitarian vessels, a high(er) level of specialization would quite likely be suggested. On the other extreme end, if they both were made from virtually the same materials and by the same production source units, then the high-level specialization in production of Tongxingqi might not be supported (at least from the raw material procurement perspective).

Second, as pottery procurement sources will be established for each investigated Hongshan household, the varying kinds and proportions of production source units (PSUs) represented from household to household will reveal to us the difference in economic connections between households and their neighbors as well as the varying capabilities that different households demonstrated in maintaining those economic ties. Analysis of upper Daling household assemblages has identified some households as higher status, based on their utilization of more elaborate and more costly pottery of several kinds (R. Drennan, Personal Communication, June 14, 2015). This gives us an opportunity to explore another interesting issue: how did pottery procurement reflect household interdependence and relate to the differentiation in household status? Special attention will be paid to correlations between households status to investigate possible economic underpinnings of status differentiation in Hongshan societies.

2. MATERIALS AND METHODOLOGY

2.1 Materials: sherds from Hongshan core zone communities

As was introduced in Chapter 1, the central theme of this dissertation project is a geochemical understanding of pottery networking in three residential areas (Sanjia, Dongshanzui, and Erbuchi) of the Hongshan core zone. Therefore, the materials to be studied in this dissertation rely entirely on pottery fragments and sherd specimens sampled from households identified in those three areas of Hongshan core zone. Surface collections of the upper Daling survey project were the only sources that yielded the sampling of sherds in this study. The 50 Hongshan core zone households delineated by intensive surface collections following regional-scale settlement analysis of the upper Daling survey project laid the foundation for sherd sampling and further analysis. Below are some brief descriptions about pottery functions and typologies, collection of surface sherds, and delineation of households in the upper Daling survey area of the core zone.

2.1.1 Hongshan core zone pottery: forms and functions

Hongshan pottery is believed to have been largely developed from the pottery making in the Xinglongwa period (6200–5400 BC) (ZHU Yanping 朱延平 2007). Pottery for both utilitarian and non-utilitarian uses have been recovered at many Hongshan settlements; in addition, the same vessel forms, styles, and functions were noticed for pottery unearthed in both the core zone and the periphery.

Utilitarian vessels in the Hongshan core zone fall into three general categories: (1) cooking vessels such as cylindrical jars (Tongxingguan 筒形罐); (2) serving vessels such as bowls (Bo 钵) and basins (Pen 盆); and (3) storage vessels such as jars (Guan 罐) and urns (Weng 瓮) (Peterson *et al.* 2014:14).

On the other hand, bottomless cylindrical jars called Tongxingqi (筒形器) are most commonly encountered in a non-utilitarian context (especially in Hongshan stone-slab graves 石板墓). Although different interpretations have been proposed for the possible uses of Tongxingqi during the Hongshan period [for example, as sacrificial utensils, as vessels being displayed at solemn ritualistic ceremonies, or as purely a musical instrument, e.g., CHEN Guoqing 陳國慶 (2003); CHEN Xingcan 陳星燦 (1990)], it is widely accepted that Hongshan Tongxingqi was produced to serve non-utilitarian purposes.

Tongxingqi 筒形器 (N2Z4A:20)

Tongxingqi 筒形器 (N2Z4L:1)

Guan 罐 (N5H14:1)

Guan 罐 (N5H41:4)

Bo 缽 (N5H14:4)

Pen 盆 (with zig-zag patterns)

Figure 2.1: Hongshan pottery vessels unearthed in the core zone
(Photos courteously provided by Mr. ZHU Da 朱達)

Both fine-paste and coarse-paste pottery were produced and used by inhabitants of Hongshan core zone communities, and there is solid evidence suggesting the use of more fine-paste pottery than coarse-paste pottery from early to late Hongshan times. For example, 54% of the pottery recovered at Xishuiquan (西水泉), a site of the middle Hongshan period, was fine-paste, while this figure climbed to approximately 80% at Dongshanzui（東山嘴）, a late Hongshan site (TENG Haijian 騰海建 2009).

Tongxingqi are all fine-paste vessels, and sometimes coated with colors (usually black). Coarse-paste vessels were most likely used for cooking and storage purposes. Some utilitarian pottery (such as serving vessels Bo and Pen) was also made from fine clays.

Figure 2.1 shows Tongxingqi and some very typical Hongshan utilitarian vessels that were most commonly encountered in the Hongshan core zone (as well as in the periphery).

2.1.2 Households identified by the upper Daling project

The upper Daling regional survey was carried out between 2009 and 2011. It has documented settlement patterns in the upper Daling River valley（大凌河上游流域）at several scales—regional, local community, and household (LU Xueming 吕學明 et al. 2010; Peterson et al. 2010, 2014). Main results of settlement study at the regional scale have been summarized above (sections 1.1 and 1.2). Work at the local community and household scale has produced the collections (mostly sherds) this dissertation will make use of.

Within the upper Daling survey region, several areas of Hongshan residential occupation (a total of about 16 ha of surface artifact scatter) were investigated in detail. These were divided between three areas (Sanjia, Dongshanzui, and Erbuchi) within the upper Daling regional survey. The Sanjia area was about 1 km to the southwest of the Dongshanzui area; the Dongshanzui area lay within about 250 m of the excavated ceremonial structures of the Dongshanzui site; and the Erbuchi area, which was in a different supra-local community or district, was about 5 km northeast of the Dongshanzui site (Peterson *et al.* 2014:29-33).

Locations of surface artifact concentrations were identified by placing survey flags at the locations of surface artifacts across each of these three areas (see Peterson 2006:23). Each surface artifact concentration identified in such a way is believed to represent a household. Each identifiable household does not necessarily correspond strictly to one individual household. It could represent individual households or small groups of households that are closely distributed. However, no effort was made to subdivide them. The term household will be consistently used throughout the dissertation to correspond to trash or garbage concentrations produced by a group of Hongshan inhabitants who lived together or relatively close to each other and therefore distinguishable from those produced by others living closer at more distant locations. In addition to the identification of surface artifact concentrations, the three areas were also subject to magnetometer survey and excavation of 1 by 2 m stratigraphic tests, which confirmed that they were locations of Hongshan residential debris (Peterson *et al.* 2014:31-44). This gives us enough confidence about who produced surface trash concentrations at where.

The largest samples of artifacts were produced by intensively surface collecting a number of groups of 5 by 5 m squares within these 16 ha of occupation. Vegetation was raked away, and the uppermost 5 cm of soil was screened to recover artifacts of all classes (Peterson *et al.* 2014:31). Varying densities of artifacts across these grids of 5 by 5 m squares made it possible to identify 50 individual artifact concentrations (or 50 "households"), including: 23 in the Sanjia area, 17 in the Dongshanzui area, and 10 in the Erbuchi area. These concentrations, as suggested earlier, represent the artifact assemblages used and discarded by one or a very few closely-spaced Hongshan households. Variation across these 50 assemblages, then, allows for an assessment of the nature and degree of variation across a number of households in a substantial area of residential occupation in the Hongshan core zone. It is these 50 identifiable Hongshan households and the sherds collected at them that comprise a pool of sherd samples this dissertation would later make use of.

Figure 2.2 shows boundaries of the upper Daling survey; the locations of Sanjia, Dongshanzui, and Erbuchi areas; and the 50 households (represented in red dots) identified in this part of the core zone.

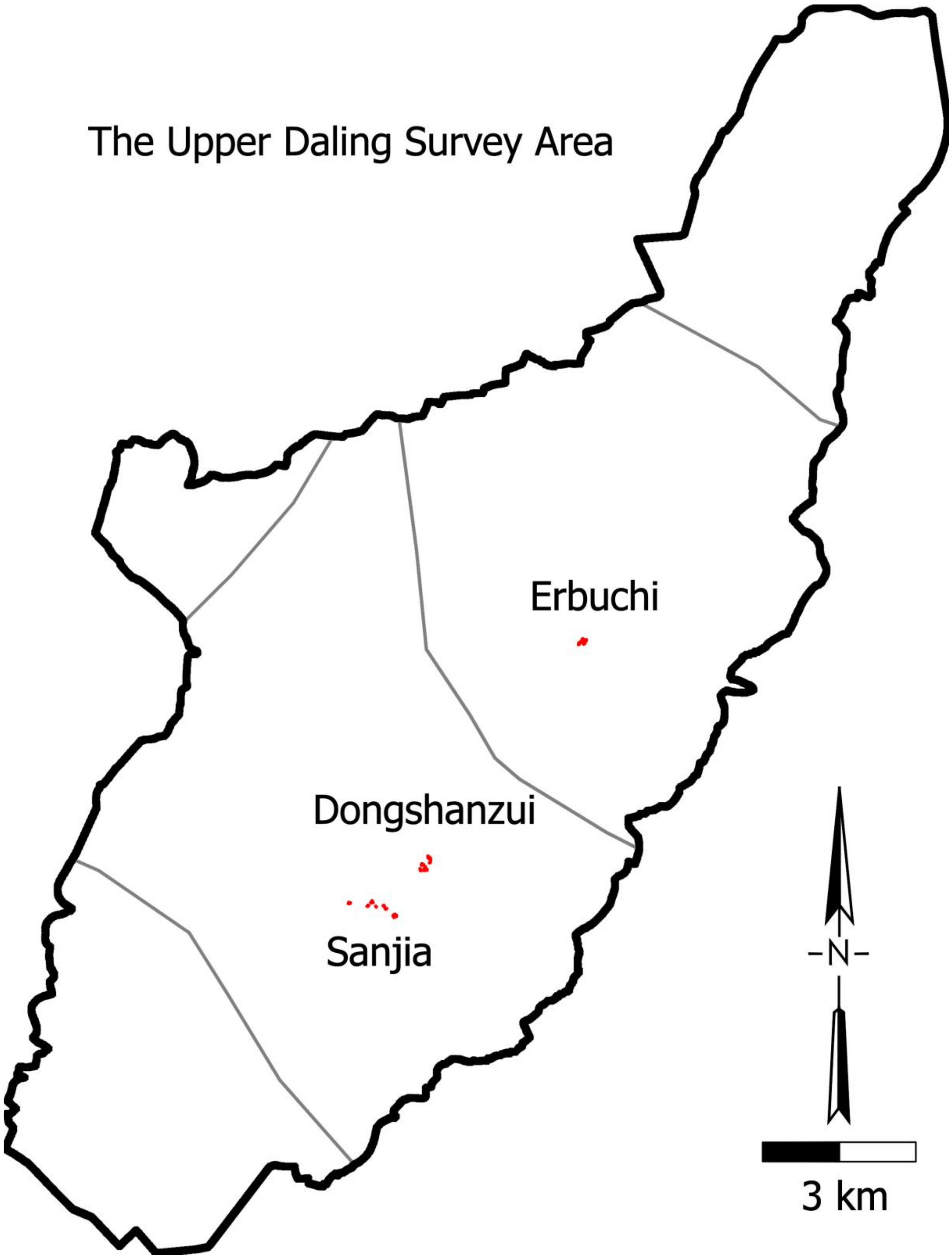

Figure 2.2: Three residential areas and 50 identifiable Hongshan households

2.2 Analytical approaches for sourcing Hongshan pottery

2.2.1 Differentiating pottery by their possible sources

A geochemical sourcing study was suggested to answer the five main research questions proposed in section 1.5. Many archaeometric studies of pottery and ceramics have shown that the term sourcing can refer to two closely related but different things: locating and differentiating. Locating is the process of relating an artifact to a geographic locus where its (main) raw materials (for example, clay, inclusions, or pigment) were exploited and used to craft this item. By contrast, differentiating is the process during which artifacts are classified by having the similarity and dissimilarity in their physical, mineralogical or geochemical properties quantitatively (or sometimes qualitatively as well) measured.

Linking an unearthed sherd to some particular locus where its raw material were exploited and/or processed is extremely difficult. A successful locating relies on many things, such as: How unique the raw materials are in terms of their physical, mineralogical, or geochemical properties? Can their uniqueness still be preserved, fully or partially, after raw materials were made into an artifact? Are there ways to qualitatively or quantitatively measure such uniqueness? And so on. The fragmentary or incomplete nature of archaeological data (especially those recovered from prehistoric sites that are not well preserved) makes locating in many cases a job impossible to accomplish. By contrast, determining the similarity or dissimilarity between one sherd and others in the same study group can be a lot easier. It simplifies the sourcing problem by focusing on sherds themselves only and requiring no sampling of (potential) pottery raw materials. In the best scenario, the groupings that describe the closeness between sherds and sherds, or between sherds and their possible raw materials, can be created by both the locating and differentiating strategies.

This dissertation chose to differentiate, rather than to locate, the sherds collected at Hongshan core zone communities. The reason for doing so is simple: no Hongshan kiln or kiln wasters were found within the 200-km^2 survey area, making impossible the sampling of pottery raw materials. Even if the Hongshan potters actually followed the least-cost theory and utilized the clay sources most readily available to their residential areas (just as potters in many archaeological/ethnographic studies did/still do), without clear material evidence suggesting resources exploitation and production activities, one cannot just include clay or soil samples collected from anywhere for sourcing studies.

2.2.2 Underlying assumptions for 'sourcing' pottery

For many researches that aimed to reconstruct the pottery production, consumption, and distribution in a given human society at a given time and place, geochemical data containing multi-elemental and quantifiable compositional information is a valuable source of information that one should first look into. For pottery, geochemical data almost always refer to elemental compositions that are inherited from soils or clays chosen by the potters at the very beginning of pottery production and later embedded into the final products (pottery vessels). Clay is a major component of soils that consists primarily of weathered rocks but also of decomposed and/or living organic matter from plants and bacteria. Therefore, the compositional data of pottery relies heavily on the geochemistry of clay, with the latter being strongly influenced by the decomposition of rocks into soils as well as by the variety and quantity of minerals finally preserved in soils or clays.

Geochemical sourcing studies on archaeological pottery and ceramics rely on some theoretical or technical assumptions. The most important one assumes that geochemical compositions of pottery/ceramic raw materials (clays) procured from different regions are distinctive and their distinctiveness can survive the process of shaping and firing clays into vessels and be quantitatively measured. Underlying this assumption are four sub-assumptions:

(1) the elemental compositions, including different elements and their concentrations, should remain quite consistent and stable and be detectable from the very beginning when a particular type of clay was chosen and procured to the last minute when vessels made from this type of clay were used, and then to the moment when they were discovered and studied again;

(2) clays procured from different geographical locations, after they were made into vessels, can still be distinguishable from each other by their featured geochemical compositions;

(3) quantifiable elemental (and sometimes mineralogical as well) compositions can be easily and reliably extracted by a particular analytical technique and method; and

(4) appropriate quantitative approaches are available and can be applied to multi-elemental compositional dataset to reveal potentially meaningful patterns that characterize clays in different locations.

The actual geochemical sourcing of clays can be straightforward or highly challenging, depending on how well the real-world data satisfy the aforementioned assumptions. Despite the potential difficulties and challenges, the geochemical sourcing of clays has been proved powerful and useful for understanding the transfer of pottery especially among groups of people living in the Neolithic period (just as the inhabitants living in households identified in the Hongshan core zone).

It is not simply because technical investigation often is the only way to understand the pottery production and distribution within and among regions and peoples, but more importantly because technological choices were limited, social and cultural needs were relatively simple, and the distribution of pottery can be relatively easy to predict, back in this period of time. For example, potters may make use of clays most readily available to them and did not put too much efforts into clay pretreatment; overexploitation of clay sources for large-scale production was rare; pottery were fired at a predictable temperature (usually below

1000 °C), which caused no or less dramatic changes in the mineralogical structure and geochemical compositions of clays.

2.2.3 Possible way of producing pottery in Hongshan times

Regional surveys and archaeological discoveries in northeastern China have revealed that inhabitants of Hongshan communities manufactured and used pottery with simple vessel forms throughout the 1500-year Hongshan period. Most of the pottery vessels were made to serve the needs for domestic activities (such as storage and serving purpose). In addition to utilitarian pottery vessels, a special type of pottery, Tongxingqi, was produced for non-utilitarian purpose, which are large bottomless pottery cylinders. Compared to utilitarian pottery, Tongxingqi vessels are much larger in size and often have beautiful decorations or line drawings on smooth surfaces with fine(r) texture, which clearly requires more labor and time to manufacture.

For most of the Hongshan occupation sites, material evidence such as kilns or kiln wasters were not found, making it difficult to recognize the pottery production activities and locate the possible sources of clays. The only reported (possible) Hongshan kilns, where dozens of reconstructable pottery vessels (mostly coarsely-made) were unearthed, were located close to the Hongshan occupation sites (Silengshan 四棱山 and Shangjifangyingzi 上機房營子) in eastern Inner Mongolia (CHEN Guoqing 陳國慶 and ZHANG Quanchao 張全超 2008; LI Gongdu 李恭篤 1977; LI Gongdu 李恭篤 and GAO Meixuan 高美璇 1987), suggesting that pottery production was carried out near the residential sites in Hongshan period.

In summary, Hongshan people (including potters and pottery consumers) very likely lived their lives and made/used pottery in a similar way as many other prehistoric groups of people did. Therefore, small-scale production of pottery using locally or easily accessible clay sources can be expected for the Hongshan societies.

2.2.4 Analytical approaches for extracting geochemical data

Extracting compositional data from ceramics (including pottery) has been made a lot easier by the introduction and application of modern instrumental analyses to archaeological materials. Case studies reporting satisfactory results from the application of these analytical methods to archaeological materials have been announced in many regions (North and South America, Europe, Africa, East and Southeast Asia, Middle East, etc.) and with different archaeological cultures in different time periods.

Conventional methods to achieve such a purpose in archaeoceramic studies include inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS), instrumental neutron activation analysis (INAA), proton induced x-ray emission (PIXE), and benchtop x-ray fluorescence spectrometry (XRF). Besides, a strong interest has also been arising in recent years for the more portable or mobile devices or instruments. For example, handheld x-ray fluorescence spectrometer (often referred to as HHXRF or pXRF, this dissertation would consistently refer to the latter) has an increasing application to generate compositional data with consistency, accuracy, and precision in measurements leading to meaningful and satisfying results.

Two candidate approaches (ICP-AES and benchtop XRF with the fusion method) came forward immediately when a compositional analysis was proposed for the purpose of revealing pottery networks in

Hongshan core zone. These two techniques were believed to better serve the needs of this dissertation project compared to INAA, PIXE, and ICP-MS because of the quantitative nature of compositional data they would provide at more affordable prices.

The pXRF analysis was not considered until a lot more sherds turned out to be needed to make statistically meaningful arguments. Neither ICP-AES nor benchtop XRF would allow a geochemical analysis of a sample size greater than 200 to be done within a few months, in view of the long, complicated sample preparation steps, the large amount of labor and time involved, and the total cost. Therefore, a few months after the ICP-AES and benchtop XRF analyses were done on a small selected sample of sherds, the pXRF analysis was also applied to the same sherds to test whether or not it would extract the <u>same kind</u> of geochemical information as ICP-AES or benchtop XRF did. If the same or similar observations could be made on the geochemical data generated by the pXRF analyzer, it would be wise to choose the pXRF analysis over ICP-AES or benchtop XRF analyses because the former would at least triple the sample size that could be analyzed by the latter two.

2.3 Establishing methodology by a series of pilot studies

2.3.1 Selection of 27 Hongshan core zone sherds

During the summer (middle August) of 2013, a small sample of sherds was selected at the Niuheliang Workstation (牛河梁工作站) in western Liaoning of northeastern China. The sample consisted of 27 sherds representing a wide variety of vessels from the 50 identifiable Hongshan core zone communities (see details about the 27 selected sherds in Table 2.1 and Table 2.2).

These 27 sherds came from both non-utilitarian and utilitarian vessels, such as Tongxingqi, Guan, Bo, Pen, and other unrecognizable utilitarian vessel forms. Nineteen (19) of the 27 sherds were fine-paste while the others were coarse-paste. The selected 27 sherds came from 15 of the 50 identifiable households, including eight (households S002, S004, S005, S006, S010, S016, S017, and S022) in the Sanjia area, six (households D101, D108, D109, D112, D113, and D114) in the Dongshanzui area, and one (household E203) in the Erbuchi area. Twenty-four (24) out of the 27 sherds were dated to the Hongshan period, while the other three were identified as Xiaoheyan sherds.

The main purpose of selecting sherds of different paste, vessel form, and periods from multiple households in the three areas was to represent in the best possible way the spatial and temporal variability of geochemistry that might characterize the three areas, where these 27 sherds and other sherds to be selected and analyzed would come from. Only when this goal was well established and the difference in geochemical profiles of pottery collected from the three areas was demonstrated would it be reasonable enough to propose distinguishing different clay sources by quantitatively comparing their geochemical data.

Otherwise, if it turned out that geochemical profiles of all sherds from the three areas showed little difference, it would make the distinction of possibly different clay sources extremely difficult or impossible. This is certainly a concern that needs to be solved before the geochemical analysis was applied to several hundred new sherds

Table 2.1: The 27 sherds selected for pilot studies

Lab No.	Households	Period	Vessel Form
DLH001	S017	Hongshan	Tongxingqi
DLH002	S017	Hongshan	Tongxingqi
DLH003	S022	Hongshan	Tongxingqi
DLH004	S010	Hongshan	Indeterminate
DLH005	S022	Hongshan	Tongxingqi
DLH006	S010	Hongshan	Pen
DLH007	S010	Hongshan	Pen
DLH008	S016	Hongshan	Indeterminate
DLH009	S006	Hongshan	Guan
DLH010	S004	Hongshan	Indeterminate
DLH011	S005	Hongshan	Tongxingqi
DLH012	S002	Hongshan	Bo
DLH013	D113	Hongshan	Tongxingqi
DLH014	D112	Hongshan	Tongxingqi
DLH015	D112	Hongshan	Bo
DLH016	D114	Hongshan	Indeterminate
DLH017	D108	Hongshan	Indeterminate
DLH018	E208	Xiaoheyan	Indeterminate
DLH019	E206	Xiaoheyan	Indeterminate

Table 2.2: (continued)

Lab No.	Households	Period	Vessel Form
DLH020	D108	Hongshan	Tongxingqi
DLH021	D109	Hongshan	Guan
DLH022	D109	Hongshan	Guan
DLH023	D109	Hongshan	Tongxingqi
DLH024	E203	Xiaoheyan	Indeterminate
DLH025	E203	Hongshan	Tongxingqi
DLH026	E203	Hongshan	Tongxingqi
DLH027	D101	Hongshan	Weng

2.3.2 Pretreatment of sherd samples and instrumentation

Sample preparation of the 27 selected sherds was carried out in the Archaeometry Laboratory at University of Chinese Academy of Sciences (UCAS, Beijing, China) between August and October 2013, for the ICP-AES and benchtop XRF analyses. Two parallel samples were cut off from each of the 27 sherds using a Micromotor-Strong 204 engraving machine (South Korea) – one for the ICP-AES analysis and the other for the benchtop XRF analysis. The remaining sherd samples were kept in sealed bags in the Archaeometry Laboratory of UCAS and not investigated by portable XRF spectrometer until the middle June of 2014 (roughly eight months after the ICP-AES and benchtop XRF analyses were done).

The procedures to prepare cut sherd samples into solution for the ICP-AES analysis followed what LI Baoping *et al.* (2003) has described in a research paper on applying ICP-MS to ancient Chinese ceramics. The procedures can be described, in order of priority, as follows: (1) Cut sherd samples weighing about 250 mg were washed in an ultrasonic cleaning tank, dried, ground into powder, and passed through a 200-mesh sieve. (2) The sieved powders were digested with distilled HF and HNO_3 acids in for 24 hours and then immersed in ultra-purified water for another 24 hours. (3) Dried samples of 100 mg were weighed out and digested in a solution of aqua regia, perchloric acid and hydrofluoric acid at 160°C for seven days to be sure all minerals (especially refractory minerals such as zircon) were dissolved. (4) The liquid solution was then heated until nearly dry and distilled by 1 ml of aqua regia.

Sample preparation for the benchtop XRF analysis (or more precisely, benchtop XRF with the fusion method) was done in a similar way as it was for the ICP-AES analysis, except that the sample was finally made into fused beads, rather than solutions. Axios-Minerals wavelength dispersive XRF spectrometer (PANalytical, the Netherlands) was used in this pilot study, whose X-ray excitation system consists of a 2.4 kW XRF Super Sharp Tube (SST) with Rh-anode. The cut sherd samples were ground into powders with agate mortar, and passed through the 360-mesh sieve. The powders were then dried to constant weight by being baked at 200℃ for 120 minutes, from which 0.5 g was selected and placed in an electric XRF bead fusion furnace until they were transformed into glass beads. The fused glass beads were fabricated using CLAISSE M4 Gas Fluxer (Canada), and the fusion agent was 5 g of lithium tetraborate ($Li_2B_4O_7$).

The pXRF analysis was carried out on the 27 remaining sherd samples in the middle June of 2014 when they were taken back to the Niuheliang Workstation (western Liaoning, China), where the original 27 sherds as well as all other sherds collected in the upper Daling project were housed. Practically speaking, the pXRF analysis can be done without any pre-treatment on sherd samples. However, most investigators usually prefer to have their samples pre-prepared in order to obtain better (more reliable and consistent) results. The sample preparation is quite easy and straightforward compared to those carried out for ICP-AES and benchtop XRF analyses. Section where two smaller sherd samples were cut off for the ICP-AES and benchtop XRF analyses was manually polished on waterproof sandpapers until a smooth surface was produced on the cross-section of sherd. For the reliability and consistency concerns, multiple (usually three) pXRF readings were collected from different areas on each sherd (this means that smooth surface on each sherd's cross section should better be three times or more as large as the 3 mm diameter X-ray beam). If the sherd's cross section turned out to be a lot thinner and would not allow for collecting (more than one) pXRF readings from it, then the sherd's surface (outside and/or inside) would be polished in the same way as for the cross-section of sherd to make sure at least two pXRF readings were collected for this particular sherd. (More details about collecting pXRF readings from Hongshan core zone pottery will be presented in section 2.5)

Once the sample preparation was done, the solutions for ICP-AES analysis and the fused beads for benchtop XRF analysis were analyzed by a Thermo Jarrell Ash IRIS Advantage (USA) ICP spectrometer and a PANalytical Axios-Minerals XRF-1500 spectrometer (the Netherlands), respectively, in the Rock/Mineral Preparation and Analysis Lab at the Institute of Geology and Geophysics (IGG), Chinese Academy of Sciences (Beijing, China). The pXRF analyzer used in this dissertation – the Niton XL3t 950 GOLDD+ (Thermo Scientific, USA) – was rented from a Thermo Fisher Scientific seller in Beijing (China).

2.3.3 Detected elements and concentrations

Major, minor, and trace elements were detected and reported by all the three analytical methods and techniques (ICP-AES, benchtop XRF, and pXRF). Following the definitions given by International Union of Pure and Applied Chemistry (IUPAC), major, minor, and trace elements refer to substance in concentration of 1–100%, <1%, and <0.01% (or <100 ppm), respectively. However, it should be pointed out that in actual scientific research the distinction among major, minor and trace elements can sometimes be subtle, that is, a by-definition trace element in one organic or inorganic matter (for example, Zirconium or Zr in soils) can also be a major or minor element in another (such as Zr in zircon) where its abundance was highly concentrated, and vice versa.

Thus, it is important to keep in mind which material systems the elements were extracted from while talking about the categories of major, minor, and trace elements. In this dissertation, for convenience of discussion, a subjective distinction was made between major and minor/trace elements, that is, detected elements whose concentrations were at 1% or higher would be treated as a single category – the major element category, while those with concentrations of less than 1% would be treated as another – the minor/trace element category.

It is also worth mentioning that, due to different principles of operation, limit of detection, signal processing, and other factors, the three analytical approaches reported different combinations of elements and different measurements of concentrations (even for the same element). Therefore, even if concentrations of one particular element were reported by all the three analytical methods, it would be wise not to compare them directly in their raw, numerical forms. One can either (1) compare different sherds for concentrations (raw, numeric forms) of the same element(s) reported by the same technique, or (2) apply standardization to measured concentrations first, and then compare standardized data from different techniques using statistical tools.

In ICP-AES analysis, concentrations of six major elements (Al, Fe, Ca, K, Na, Mg, with oxides expressed in weight percentage, %) and fourteen minor/trace elements (Ti, Mn, P, with oxides expressed in weight percentage, %; Co, Cu, Li, Mo, Ni, Sr, U, V, Y, Zn and Zr, in ppm) were determined for each sherd specimen. Results of ICP-AES analysis are shown in Table 2.3, Table 2.4, and Table 2.5.

For the benchtop XRF analysis, concentrations of seven major elements (Si, Al, Fe, Mg, Ca, Na, K, with oxides expressed in weight percentage, %) and eighteen minor/trace elements (Ti, Mn, P, with oxides expressed in weight percentage, %; Ba, Co, Cr, Cu, Ga, Nb, Ni, Pb, Rb, Sr, Th, V, Y, Zn, and Zr, in ppm) were measured for each of the 27 sherds. Results are shown in Table 2.6, Table 2.7, and Table 2.8.

Concentrations of up to 33 elements are reported in each pXRF reading; however, only eleven of them (two major elements such as Fe and K; and nine minor/trace elements such as Ba, Zr, Sr, Rb, Zn, Ni, Mn, Ti, and Ca) were consistently and reliably recorded (see section 3.1 for a detailed discussion of how these eleven elements was determined). Results of pXRF analysis are shown in Table 2.9 and Table 2.10.

Table 2.3: ICP-AES results of the 27 sherds (in %)

Lab No.	Households	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
DLH001	S017	12.46	6.67	0.62	0.73	1.86	2.65	0.91	0.10	0.13
DLH002	S017	16.29	6.08	1.58	1.57	1.92	2.94	0.81	0.11	0.35
DLH003	S022	16.06	6.32	1.47	1.18	1.70	2.99	0.82	0.11	0.12
DLH004	S010	12.67	5.58	1.17	0.85	1.42	2.28	0.83	0.07	0.39
DLH005	S022	13.73	5.58	0.69	0.91	1.49	2.56	0.76	0.09	0.19
DLH006	S010	11.36	4.33	1.10	0.56	1.07	2.25	0.65	0.06	0.12
DLH007	S010	14.70	5.70	1.20	1.07	1.92	2.67	0.83	0.07	0.34
DLH008	S016	15.58	6.76	1.17	0.56	0.95	2.69	0.95	0.09	0.07
DLH009	S006	14.45	5.40	1.36	0.95	1.34	2.41	0.74	0.08	0.15
DLH010	S004	8.41	3.24	0.66	0.99	1.12	2.00	0.60	0.05	0.27
DLH011	S005	6.97	2.72	0.59	0.60	1.18	1.92	0.78	0.04	0.12
DLH012	S002	16.31	6.49	0.68	1.04	1.79	2.75	0.93	0.11	0.31
DLH013	D113	17.44	5.95	1.89	2.70	2.50	3.00	0.88	0.09	0.08
DLH014	D112	5.20	4.55	0.33	1.75	1.44	2.39	0.74	0.06	0.59
DLH015	D112	10.22	4.05	1.14	0.72	1.26	2.25	0.79	0.06	0.10
DLH016	D114	10.77	4.27	0.82	0.91	1.20	2.00	0.78	0.06	0.22
DLH017	D108	7.34	3.71	0.46	0.44	0.68	2.61	0.63	0.05	0.26
DLH018	E208	18.40	7.59	1.06	1.99	1.51	2.24	1.14	0.06	0.60
DLH019	E206	18.13	5.86	1.55	1.92	2.38	2.90	0.77	0.07	0.17
DLH020	D108	14.63	6.34	1.02	1.12	1.97	2.69	1.02	0.10	0.24
DLH021	D109	15.52	4.92	0.87	1.69	1.31	2.56	0.77	0.05	0.59
DLH022	D109	19.82	6.44	1.04	2.06	1.78	3.34	0.85	0.07	0.36
DLH023	D109	14.61	5.87	0.86	1.25	1.70	2.52	0.91	0.08	0.18
DLH024	E203	12.07	3.98	1.42	1.50	2.12	2.51	0.54	0.05	0.17
DLH025	E203	13.32	4.72	0.83	1.13	1.27	2.15	0.72	0.05	0.46
DLH026	E203	8.23	3.51	0.88	0.96	1.21	2.26	0.72	0.04	0.15
DLH027	D101	8.49	4.01	0.88	0.93	2.73	2.09	0.72	0.04	0.04

Table 2.4: (continued, in ppm)

Lab No.	Households	Co	Cu	Li	Mo	Ni	Sr
DLH001	S017	45.30	25.35	63.93	16.10	50.40	50.00
DLH002	S017	65.30	27.95	82.87	10.65	43.65	183.96
DLH003	S022	57.10	21.50	74.20	0.00	61.95	132.83
DLH004	S010	61.40	13.30	56.40	0.00	62.90	106.79
DLH005	S022	51.50	10.30	64.27	17.20	52.30	127.96
DLH006	S010	30.45	3.05	52.27	0.00	4.15	83.38
DLH007	S010	50.75	11.20	46.67	39.60	32.10	160.75
DLH008	S016	70.25	16.80	82.27	0.00	56.15	80.63
DLH009	S006	48.35	13.05	59.20	4.60	46.60	134.71
DLH010	S004	27.75	0.00	34.33	15.55	21.50	107.88
DLH011	S005	37.25	0.00	27.93	0.00	17.65	79.38
DLH012	S002	56.20	17.20	77.73	0.00	42.70	153.54
DLH013	D113	48.50	16.75	79.47	0.00	54.25	214.63
DLH014	D112	0.00	47.70	39.27	33.35	43.65	37.08
DLH015	D112	36.30	2.15	40.07	0.00	29.20	108.13
DLH016	D114	47.90	2.15	33.73	26.15	17.65	108.96
DLH017	D108	48.50	1.75	22.27	0.00	0.00	58.42
DLH018	E208	66.65	19.35	36.67	0.00	19.55	226.25
DLH019	E206	49.40	21.90	100.13	14.25	34.95	318.79
DLH020	D108	62.60	22.35	78.33	5.20	55.20	189.46
DLH021	D109	33.50	13.75	33.73	7.05	61.00	186.71
DLH022	D109	39.05	21.05	57.40	0.00	30.15	258.96
DLH023	D109	63.05	24.10	64.33	0.00	57.15	171.75
DLH024	E203	43.85	9.45	111.07	8.20	12.80	245.46
DLH025	E203	32.15	4.75	34.20	0.00	17.65	160.29
DLH026	E203	23.70	3.45	12.47	17.40	16.65	96.92
DLH027	D101	24.05	11.60	35.13	33.35	34.00	75.33

Table 2.5: (continued, in ppm)

Lab No.	Households	U	V	Y	Zn	Zr
DLH001	S017	160.00	239.42	6.05	173.61	103.25
DLH002	S017	0.00	219.88	12.13	133.17	29.04
DLH003	S022	0.00	278.58	4.95	77.33	24.39
DLH004	S010	65.00	164.33	16.55	79.17	11.68
DLH005	S022	0.00	214.42	0.00	94.17	18.61
DLH006	S010	0.00	168.75	2.20	46.89	0.04
DLH007	S010	0.00	230.75	12.13	143.17	26.71
DLH008	S016	0.00	252.50	1.65	101.61	77.75
DLH009	S006	10.00	235.29	6.03	157.50	6.93
DLH010	S004	40.00	82.79	12.13	23.17	24.39
DLH011	S005	0.00	89.33	10.48	1.44	45.29
DLH012	S002	0.00	301.46	3.85	426.00	41.79
DLH013	D113	0.00	279.67	3.85	118.94	76.57
DLH014	D112	0.00	118.71	0.00	1264.00	102.11
DLH015	D112	0.00	126.29	18.75	39.94	10.46
DLH016	D114	0.00	128.50	7.73	99.72	19.75
DLH017	D108	0.00	74.08	3.85	78.06	32.50
DLH018	E208	0.00	293.83	24.25	178.39	162.43
DLH019	E206	0.00	279.67	1.10	492.22	99.79
DLH020	D108	66.00	224.21	4.40	444.78	77.75
DLH021	D109	0.00	242.67	14.88	81.83	49.93
DLH022	D109	0.00	336.21	4.95	165.28	89.36
DLH023	D109	0.00	273.17	0.00	115.94	56.86
DLH024	E203	0.00	127.42	0.00	173.22	129.93
DLH025	E203	0.00	190.50	0.00	103.11	51.07
DLH026	E203	96.00	110.00	2.20	40.67	15.11
DLH027	D101	0.00	128.50	0.00	480.56	68.46

Table 2.6: Benchtop XRF results of the 27 sherds (in %)

Lab No.	Households	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
DLH001	S017	65.59	0.85	17.78	6.70	0.12	1.48	1.21	1.38	2.81	0.15
DLH002	S017	66.49	0.85	16.04	6.15	0.12	1.33	1.71	1.37	2.79	0.36
DLH003	S022	66.26	0.82	17.28	6.37	0.12	1.38	1.42	1.55	2.85	0.13
DLH004	S010	65.36	0.86	16.73	6.22	0.09	1.26	1.20	1.42	2.38	0.40
DLH005	S022	64.94	0.82	16.92	6.23	0.11	1.01	1.51	1.58	2.74	0.22
DLH006	S010	66.95	0.82	16.93	6.22	0.10	1.38	0.96	1.16	2.88	0.17
DLH007	S010	67.13	0.82	16.10	5.88	0.08	1.22	1.39	1.59	2.60	0.36
DLH008	S016	64.15	0.89	18.34	6.80	0.10	1.52	0.94	0.82	2.82	0.09
DLH009	S006	68.46	0.83	16.47	6.17	0.09	1.32	1.17	1.12	2.83	0.17
DLH010	S004	65.95	0.82	15.51	5.81	0.10	1.07	1.93	1.47	2.53	0.39
DLH011	S005	67.61	0.85	15.66	5.77	0.10	1.17	1.54	1.75	2.72	0.22
DLH012	S002	62.98	0.84	16.79	6.23	0.11	0.75	1.31	1.48	2.67	0.32
DLH013	D113	69.03	0.81	15.51	5.51	0.09	1.44	2.49	1.53	2.75	0.10
DLH014	D112	66.63	0.82	16.31	5.73	0.07	1.45	1.48	1.49	2.52	0.71
DLH015	D112	68.99	0.83	16.38	5.93	0.09	1.55	1.23	1.45	2.80	0.14
DLH016	D114	65.82	0.84	16.91	6.40	0.10	1.12	1.52	1.47	2.68	0.31
DLH017	D108	65.41	0.79	16.85	5.97	0.10	1.04	1.13	1.06	2.99	0.38
DLH018	E208	58.27	1.00	17.74	7.15	0.06	0.87	1.90	1.41	2.31	0.60
DLH019	E206	62.19	0.74	16.75	5.80	0.08	1.22	1.94	1.93	2.79	0.19
DLH020	D108	66.07	0.89	17.08	6.22	0.10	1.09	1.44	1.50	2.58	0.25
DLH021	D109	64.35	0.79	15.52	5.47	0.06	0.76	1.92	1.06	2.76	0.65
DLH022	D109	59.46	0.75	17.36	5.99	0.07	0.78	1.83	1.36	3.38	0.37
DLH023	D109	65.35	0.83	16.76	6.12	0.08	1.50	1.83	1.44	2.16	0.26
DLH024	E203	65.08	0.66	15.18	5.16	0.07	1.54	1.88	2.00	2.86	0.23
DLH025	E203	63.66	0.89	16.62	6.14	0.07	0.91	1.39	1.30	2.52	0.56
DLH026	E203	67.60	0.84	15.97	5.73	0.08	1.19	1.49	1.52	2.68	0.19
DLH027	D101	67.02	0.84	17.49	6.55	0.07	1.39	1.21	1.06	2.67	0.09

Table 2.7: (continued, in ppm)

Lab No.	Households	Ba	Co	Cr	Cu	Ga	Nb	Ni	Pb
DLH001	S017	629.70	16.95	82.00	33.91	23.62	17.36	40.29	27.55
DLH002	S017	876.55	14.85	79.54	19.47	17.97	20.29	33.74	27.09
DLH003	S022	750.49	13.83	82.37	26.89	22.11	18.30	37.45	31.07
DLH004	S010	623.20	15.30	89.65	39.54	20.14	18.20	42.13	33.70
DLH005	S022	901.29	15.19	80.49	22.81	20.31	17.42	39.57	33.01
DLH006	S010	688.43	16.30	80.80	33.96	22.41	17.51	45.21	30.25
DLH007	S010	815.20	13.99	85.00	15.66	18.22	15.87	34.80	28.72
DLH008	S016	654.55	15.12	92.90	30.93	23.51	17.79	39.12	21.82
DLH009	S006	711.10	17.14	78.35	26.49	23.59	15.56	39.08	34.69
DLH010	S004	938.57	14.84	73.48	28.06	18.01	18.68	33.47	20.77
DLH011	S005	732.04	14.22	76.30	24.55	17.19	18.66	35.42	28.40
DLH012	S002	825.05	16.90	80.88	22.55	17.13	17.04	41.14	25.05
DLH013	D113	820.98	12.92	74.53	24.36	18.78	15.92	34.52	25.51
DLH014	D112	771.27	9.40	79.70	26.02	18.42	15.23	30.40	30.34
DLH015	D112	680.49	12.78	77.96	37.04	18.81	18.12	30.70	25.20
DLH016	D114	803.63	13.90	77.69	20.76	19.01	18.32	36.06	26.21
DLH017	D108	767.71	13.91	76.19	32.49	20.65	19.69	40.87	31.91
DLH018	E208	747.20	12.74	74.52	22.65	21.00	22.34	33.89	22.12
DLH019	E206	872.53	14.02	71.08	36.73	19.56	18.38	31.85	21.39
DLH020	D108	950.01	16.92	79.12	23.28	16.68	17.96	39.63	31.95
DLH021	D109	1037.41	10.36	72.86	17.57	16.32	15.68	31.95	31.84
DLH022	D109	1136.18	14.86	73.91	28.80	20.74	19.14	36.28	31.57
DLH023	D109	590.09	13.82	81.84	28.85	16.36	14.57	32.94	24.86
DLH024	E203	951.76	11.47	67.13	33.32	17.04	14.91	31.75	29.26
DLH025	E203	885.08	16.62	69.49	23.09	19.91	17.56	39.83	23.92
DLH026	E203	761.59	13.38	71.60	21.91	17.11	15.79	35.58	16.96
DLH027	D101	649.76	14.68	83.87	17.85	21.13	17.26	35.17	28.60

Table 2.8: (continued, in ppm)

Lab No.	Households	Rb	Sr	Th	V	Y	Zn	Zr
DLH001	S017	115.93	131.40	24.36	93.05	32.90	89.68	306.56
DLH002	S017	116.73	186.03	20.30	92.66	34.68	78.45	357.45
DLH003	S022	112.75	143.63	10.98	103.88	27.72	81.16	290.37
DLH004	S010	83.26	146.04	12.11	91.17	29.35	83.99	323.70
DLH005	S022	102.08	170.75	17.96	97.37	31.18	73.81	292.20
DLH006	S010	106.64	126.90	14.62	101.13	30.91	92.51	291.28
DLH007	S010	102.37	186.49	26.87	82.17	33.66	73.37	307.56
DLH008	S016	113.24	114.34	26.38	87.96	35.88	92.21	320.02
DLH009	S006	120.47	149.27	29.35	99.56	34.19	90.02	297.39
DLH010	S004	89.95	183.55	16.62	97.64	33.44	72.25	340.15
DLH011	S005	97.06	177.13	13.00	73.38	33.96	74.56	316.37
DLH012	S002	100.63	165.37	28.52	91.62	35.07	73.81	304.50
DLH013	D113	115.36	174.31	22.12	90.89	30.89	72.60	321.51
DLH014	D112	100.46	185.56	27.01	107.05	31.72	73.99	314.25
DLH015	D112	112.56	164.15	12.71	104.16	32.05	75.26	306.79
DLH016	D114	105.58	159.12	17.99	101.73	32.36	80.27	299.64
DLH017	D108	115.77	135.47	16.07	94.87	34.27	97.56	302.26
DLH018	E208	60.72	181.49	17.64	110.78	37.46	89.92	302.71
DLH019	E206	81.84	258.48	13.63	87.22	26.99	91.27	257.41
DLH020	D108	83.87	185.55	17.11	67.24	32.89	73.22	322.48
DLH021	D109	93.08	173.38	23.75	105.35	31.04	74.90	313.21
DLH022	D109	97.23	188.36	18.27	97.79	30.39	100.63	268.40
DLH023	D109	68.23	180.47	25.59	103.61	34.20	91.34	319.57
DLH024	E203	81.96	250.51	11.65	63.50	24.47	85.62	242.26
DLH025	E203	83.93	166.30	18.66	95.33	29.58	79.61	303.28
DLH026	E203	107.51	173.63	20.00	84.37	32.52	75.37	330.63
DLH027	D101	111.56	123.87	12.27	108.66	26.46	89.56	257.83

Table 2.9: pXRF results of the 27 sherds (in ppm)

Lab No.	Households	Ba	Zr	Sr	Rb	Zn	Ni
DLH001	S017	963.33	332.85	122.01	103.91	81.92	2791.08
DLH002	S017	1064.73	396.21	170.47	109.94	69.33	626.93
DLH003	S022	1118.44	336.02	142.11	108.40	72.42	173.32
DLH004	S010	852.43	83.53	91.50	16.88	104.00	315.48
DLH005	S022	1082.87	333.95	162.12	99.25	67.15	2899.98
DLH006	S010	1132.94	313.71	172.42	108.15	76.10	3194.48
DLH007	S010	974.54	326.60	168.31	82.42	52.35	55.91
DLH008	S016	811.64	368.04	125.36	107.54	88.27	456.10
DLH009	S006	1116.92	345.62	158.01	123.31	70.61	863.00
DLH010	S004	1176.80	358.72	168.31	82.23	61.16	2783.24
DLH011	S005	931.87	178.26	125.03	41.84	85.88	152.60
DLH012	S002	1081.08	344.12	156.29	91.32	65.25	3766.72
DLH013	D113	1054.64	299.49	149.52	81.76	71.00	133.34
DLH014	D112	967.90	343.86	171.95	80.62	57.80	2059.55
DLH015	D112	823.00	357.67	161.50	106.41	73.47	1869.50
DLH016	D114	1100.58	133.91	109.44	32.64	86.08	135.66
DLH017	D108	1100.19	294.40	149.23	117.24	80.15	1100.20
DLH018	E208	823.57	332.95	173.96	55.50	73.79	1065.23
DLH019	E206	1254.79	273.67	292.95	89.48	80.56	515.12
DLH020	D108	1141.87	295.09	169.71	68.82	78.18	739.98
DLH021	D109	1317.39	250.16	183.95	76.55	57.54	1299.28
DLH022	D109	1434.71	259.97	193.31	96.44	53.45	2152.74
DLH023	D109	965.94	361.90	159.42	94.84	61.96	1063.33
DLH024	E203	1143.25	283.28	272.87	92.44	66.10	462.74
DLH025	E203	1248.04	332.40	182.40	78.98	67.44	868.45
DLH026	E203	798.94	338.10	160.70	54.69	66.80	1767.45
DLH027	D101	916.16	306.03	130.77	105.09	76.07	331.77

Table 2.10: (continued, in ppm)

Lab No.	Households	Fe	Mn	Ti	Ca	K
DLH001	S017	44539.96	883.67	2470.17	4248.01	12681.86
DLH002	S017	41904.98	886.76	3771.89	6702.56	16342.42
DLH003	S022	43906.02	988.51	2113.85	5982.74	13875.15
DLH004	S010	7511.33	678.75	3871.22	5801.22	13939.55
DLH005	S022	43111.45	951.54	1627.98	6294.67	9605.67
DLH006	S010	41022.03	742.41	1452.19	5771.70	14538.39
DLH007	S010	36481.19	619.86	745.13	5071.95	7379.54
DLH008	S016	52394.20	2335.55	3489.04	3747.32	14355.28
DLH009	S006	40196.64	794.20	3348.23	5326.54	22016.13
DLH010	S004	35323.36	808.92	2188.51	6056.58	10469.16
DLH011	S005	19141.86	754.51	3085.52	6552.16	11495.83
DLH012	S002	42074.23	798.90	1897.52	6188.15	11576.60
DLH013	D113	29558.83	707.06	3980.91	8638.41	8142.07
DLH014	D112	37412.72	626.02	3220.05	5540.72	12114.05
DLH015	D112	40768.53	702.81	2511.53	4674.42	12946.99
DLH016	D114	14949.72	695.50	2695.33	7020.62	11043.26
DLH017	D108	36091.88	765.46	3024.13	3961.49	17321.37
DLH018	E208	49072.60	500.26	4270.10	8905.74	12984.63
DLH019	E206	39664.50	731.91	2466.97	8754.63	13488.84
DLH020	D108	33981.93	866.77	3308.82	6345.56	13372.36
DLH021	D109	27000.01	447.01	2416.03	6753.65	13720.05
DLH022	D109	29406.00	452.26	2146.76	7024.47	15546.06
DLH023	D109	36955.42	660.90	2196.68	5851.60	12012.97
DLH024	E203	34959.69	629.64	2158.55	8181.35	16014.41
DLH025	E203	38695.81	730.34	3759.48	6060.61	13983.16
DLH026	E203	38774.79	600.13	3261.37	7158.53	10302.70
DLH027	D101	47354.09	581.75	2521.82	5966.27	10774.99

2.3.4 HCA of standardized ICP-AES, XRF, and pXRF data

Different combinations of elements reported by the three analytical approaches and their concentration values for the 27 sherds can be treated as three individual geochemical datasets (one for ICP-AES results, one for benchtop XRF results, and yet another one for pXRF results). Hierarchical cluster analysis (HCA) provides an opportunity to explore the patterned distribution of these 27 sherds by examining how each single sherd was at first aligned separately and then grouped into clusters with other sherds based on the similarity/dissimilarity in their geochemical compositions.

As was suggested in section 2.3.3, measurements of concentrations of chosen elements in each datasets were standardized before the HCA. The standardization was done first by computing z-scores by subtracting the mean concentration of an element from concentration recorded for that particular element in each sherd specimen (whether it is a ICP-AES, a benchtop XRF, or a pXRF one), then by dividing the difference by the standard deviation of the batch of readings for that particular element.

Once the z-score standardization was done, HCA was applied to each of the three z-scored datasets to produce clustering trees (also known as dendrograms) with different distance calculation methods (clustering algorithms). After that, dendrograms produced by different clustering algorithms (Single Linkage, Complete Linkage, Ward's method, and so forth) and on different datasets were compared to each other for general patterns. It turned out that, whatever cluster methods were used, the general patterns of sherds being clustered together remained quite steady, even though the whole structure of produced dendrograms did vary to some degree as the clustering algorithm was changed from one to another. Generally speaking, the Complete Linkage method seemed to produce dendrograms with the clearest structure.

Dendrograms shown in Figure 2.3, Figure 2.4, and Figure 2.5 were produced by measuring distances of clusters with the Complete Linkage method on standardized ICP-AES, benchtop XRF, and pXRF datasets, respectively. Clusters of sherds showed up clearly as soon as the clustering process started. For sherds in each cluster identifiable at a certain distance, they were grouped simply because they have the most similar clay geochemistry and look more like each other geochemically than sherds in other clusters.

It must be pointed out that not every cluster identifiable at any distance can serve as a meaningful unit of analysis. Taking the 27 sherds as an example, we definitely do not want to study 27 clusters consisting of one single sherd in each, as it will reveal too many details and contribute almost nothing to advancing our understanding. The same disastrous result can be expected if we consider the 27 sherds as coming from one single cluster. We would like to have something in between (that is, a more proper way to delineate a more reasonable number of clusters) to help us recognize patterns underlying the archaeological (pottery) data. It is for this particular reason that we introduced here the concepts of <u>compositional group</u> and <u>production source unit</u>.

A compositional group is a group consisting of sherds that would look most alike in their geochemical compositions and, most importantly, convey <u>meaningful</u> information about human behaviors while remaining distinguishable as a whole from another group compositionally. By '<u>meaningful</u>', it requested that a compositional group should be interpretable beyond the geochemical or mineralogical reason; that is to say, we would be more interested to know whether there were technological, cultural, economic, or other incentives and causes that led to the clusters of sherds. Therefore, the delineation of a compositional group should not simply and solely rely on the similarity in sherds' geochemical compositions, but also on whether it can be interpreted to reveal at least some aspects of human behaviors.

Taking the argument about compositional group one step further, as we believe that a compositional group conveys important information about human behaviors, it seems reasonable to argue that a compositional group represents some technological, cultural, or social traits that were maintained and shared by a particular group of people. Such a group of people, wherever they were and however they were related (religiously, economically, or sociopolitically), demonstrated a higher degree of similarity and homogeneity in their pottery making activities and their final products (pottery vessels) and therefore distinguished themselves from those who tended to produce pottery that would characterize another compositional group. Even though it sounds a very conceptual and intuitive idea and would be really difficult to prove with pottery evidence only, we would still argue, for the reasons discussed above, that a compositional group indicates a production source unit (a more formal term for "a particular group of people" and with the equal meaning as the term "pottery producer", if it sounds not too outrageous). It could be said that, the more meaningful compositional groups of sherds were identifiable, the more clay sources or pottery procurement sources would probably be utilized in producing the investigated pottery and the more possible production source units (or pottery producers) would therefore be indicated. (Some additional discussions on what a production source unit really means in this dissertation would be presented in section 5.2 in my response to the Research Question 2).

Following the discussions above, a few production source units (six for dendrograms produced on ICP-AES and pXRF results, and seven for the one produced on benchtop XRF results) were identified on each of the three dendrograms. A quick observation implied that each production source unit often combined sherds from different households and different occupation areas, and included sherds only from the same residential area under very rare circumstances (such as PSU06 in Figure 2.3 or PSU03 in Figure 2.4). Therefore, sherds collected at most households should have come very likely from multiple production source units, and very few households could have consumed sherds made from geochemical compositions characteristic of one production source unit.

On the other hand, the overall distribution of the 27 sherds across the dendrograms showed a clear correspondence to the locations where each household to which the sherd belonged to came from. For example, in Figure 2.3, PSU06 contained sherds nearly all (87.5%) coming from the Sanjia area to the south, while PSU04 and PSU05 occurred both in the Sanjia area (33.3%) and in the more central Dongshanzui area (66.6%). PSU02 and PSU03 consisted mostly (83.3%) of sherds from the Erbuchi area to the north, along with one sherd (16.7%) from the Dongshanzui area. It is obvious that the geochemical differences between sherds are not exclusive to the three areas; however, their distribution across the clusters mimics in broad terms the geographical locations of these areas, which makes sense if these clusters or production source units indicate the exploitation of raw materials in different locations.

One more important thing worth mentioning is that sherds from the same household or from households spatially close to each other within the same occupation area sometimes tend to be grouped immediately into small compositional groups or production source units as the clustering progress started, and then mixed with sherds from other areas when larger clusters were formed. For example, sherds selected from households S017, S016, and S022 in the Sanjia area, from households D108 and D109 in the Dongshanzui area, or from households E203 and E208 in the Erbuchi area, fell into the same production source unit soon after the clustering process had started. This observation not only confirmed the basic assumption that sherds from the same occupation area would more likely be grouped together to indicate the same production source units, but also suggested that production source units comprising of mixed sherds from different households and/or different occupation areas might be the right evidence that inhabitants of Hongshan core zone communities should have differential access to pottery made from different clays by different potters and consumed them in different ways.

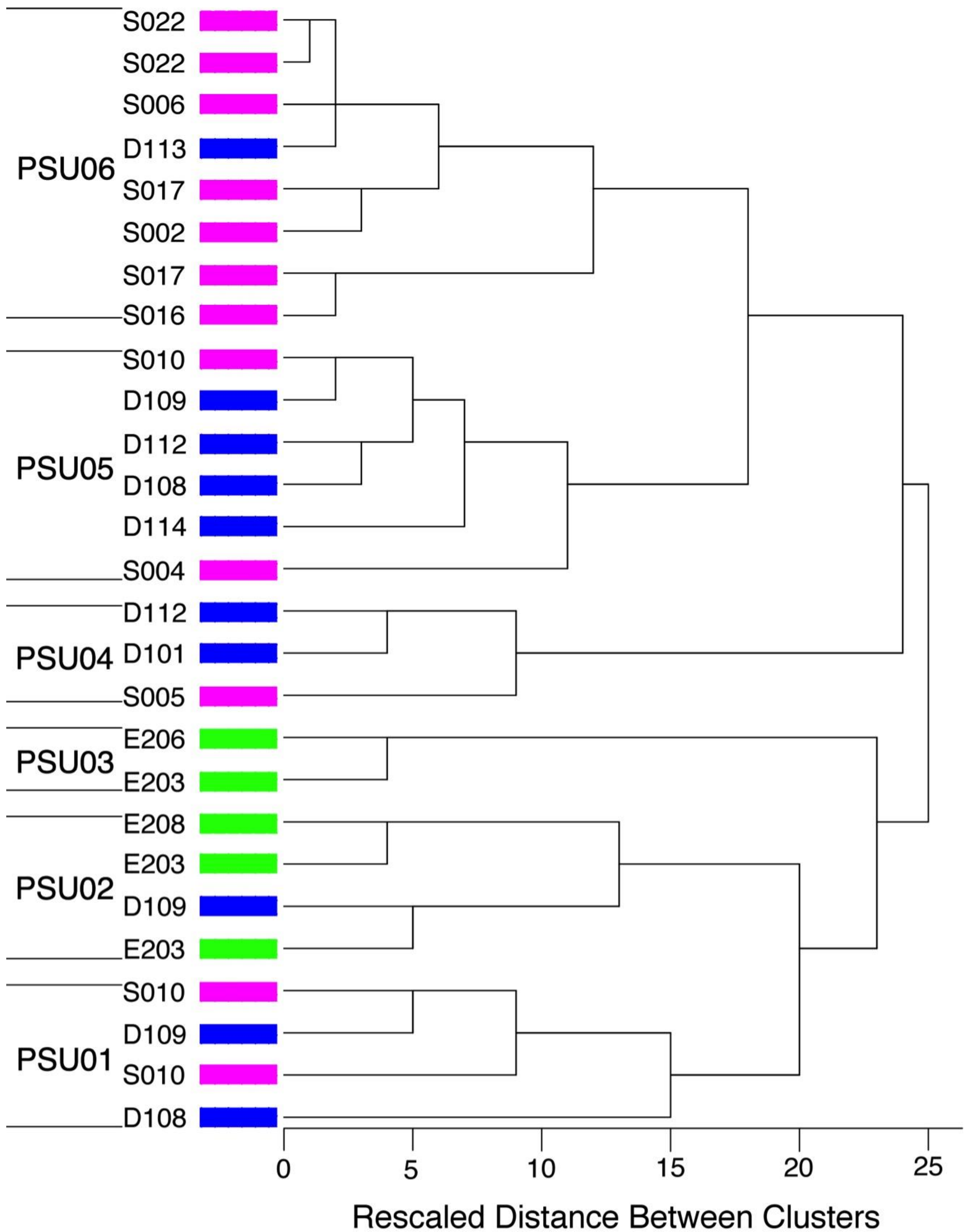

Figure 2.3: Dendrogram produced on z-scored ICP-AES data

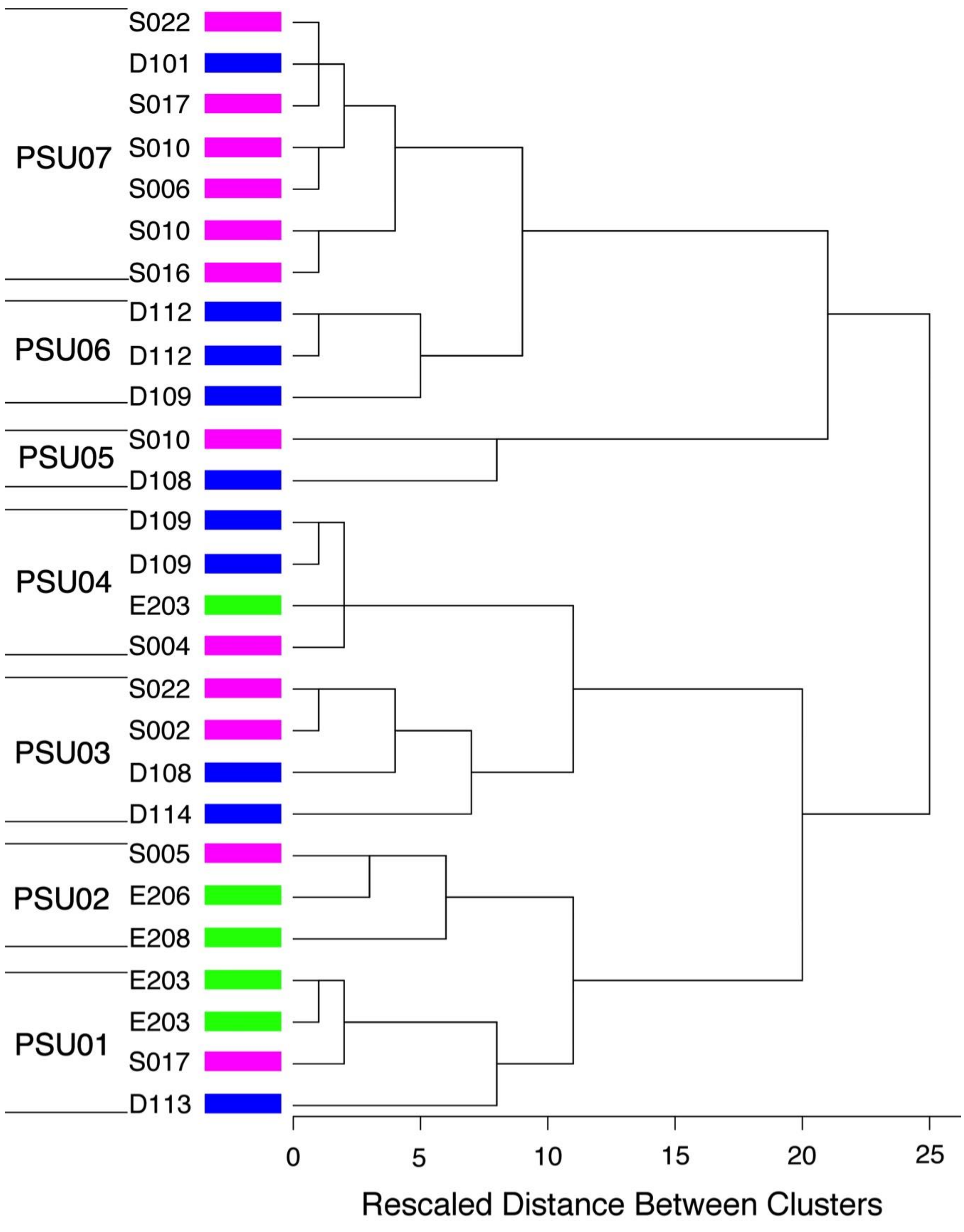

Figure 2.4: Dendrogram produced on z-scored benchtop XRF data

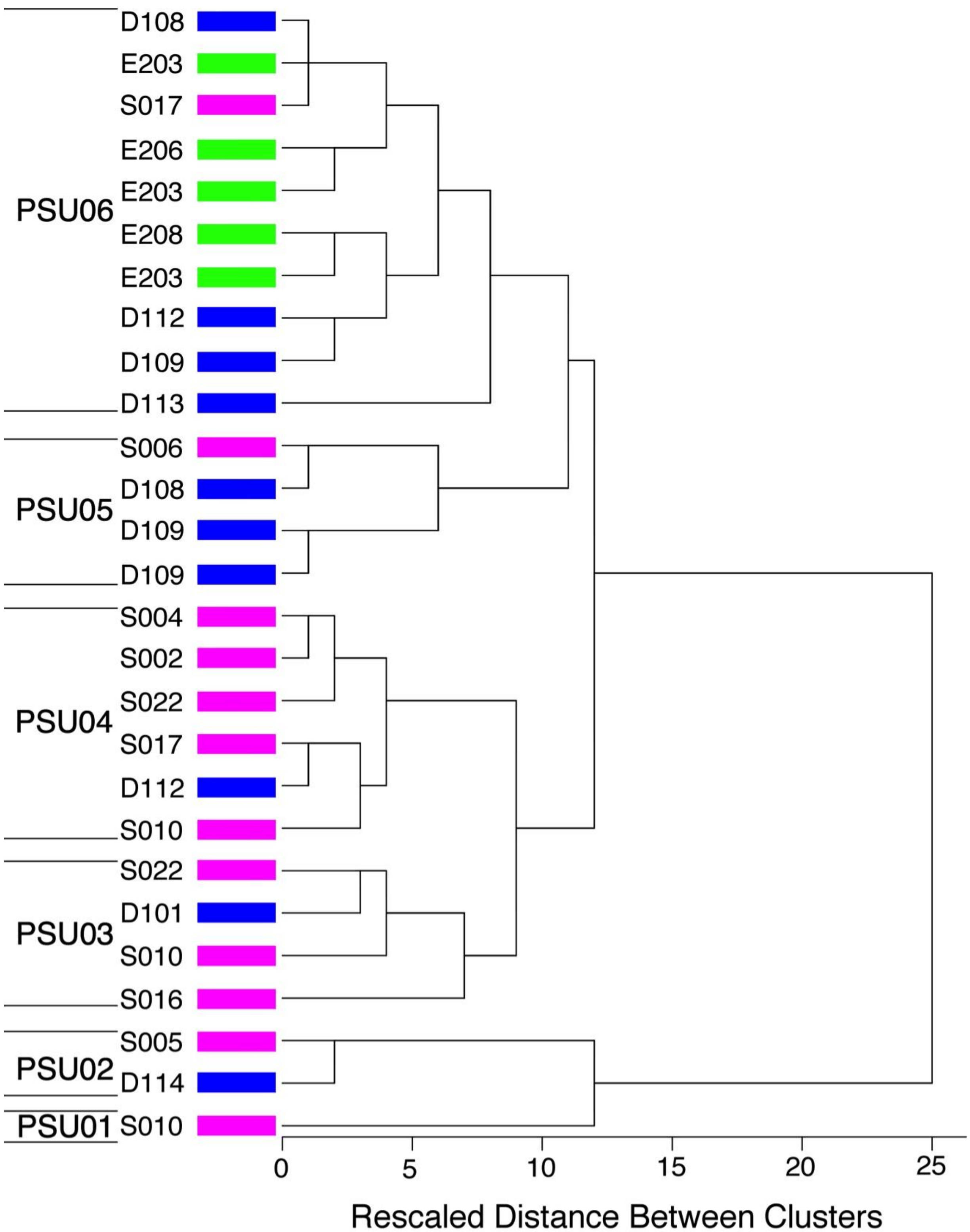

Figure 2.5: Dendrogram produced on z-scored pXRF data

2.3.5 Determining the final methodology

The results of hierarchical cluster analyses could be summarized into the following statements: the general patterned distribution of Sanjia and Erbuchi sherds being distributed more compactly toward each end of the dendrogram, with Dongshanzui sherds being well mixed in between, shows some degree of match with the geographical distribution and spatial relationships of the three areas – that is, Sanjia and Erbuchi being far away from each other, with Dongshanzui located in between (although it is in real world much closer to Sanjia than to Erbuchi). Given that such observations were made only on a very small sample (27 sherds), it seemed quite impossible to make any ambitious and conclusive judgment about the mode of pottery production and distribution in the Sanjia, Dongshanzui, and Erbuchi areas, not to mention the entire Upper Daling survey area.

However, the pilot studies of the 27 sherds indicated a possibility of approaching this final goal by performing multivariate statistical analysis on geochemical data extracted from Hongshan core zone pottery. If the patterned distribution noticed for the 27 sherds would still persist when the sample size was enlarged to a few dozen times larger and hundreds of sherds were selected for compositional analysis following the same strategy as applied to the 27 sherds, some tantalizing clues to answer this dissertation's research questions (as described in section 1.5) would be confirmed. For example, it would more likely be a general phenomenon that sherds collected (or consumed) within the same area had been largely made from clays that were geochemically similar to each other but also geochemically more different from those that had been used for producing pottery to be consumed in the other two areas. In other words, sherds collected within the same area would look more alike in their geochemical compositions, and therefore tend to be grouped into the same compositional groups. This would lay the basis to argue for the distribution of pottery among different households and different residential areas if sherds consumed in one household (or area) turned out to fall into compositional groups that were characterized by sherds intensively consumed in other households (or areas).

Last but not the least, it is important to observe that the dendrograms produced by performing hierarchical cluster analysis on ICP-AES, benchtop XRF, and pXRF data all revealed the same kind or nature of information. By the same 'kind' or 'nature', it refers to several different things: (1) the general tendency that sherds collected within the same area seemed geochemically more alike but in the meantime more different from those from the other two areas in their geochemical compositions; (2) the similar pattern that sherds collected at the same household(s) tended to look more alike; and (3) the common feature that sherds collected at the same household often fell into several meaningful clusters, suggesting the household's access to multiple production source units, rather than a single one.

Therefore, at least in the sense of extracting geochemical information from sherds and relating them to the production and distribution of pottery, pXRF achieved the same level of conclusion as ICP-AES or benchtop XRF did. Considering that pXRF would make possible a much larger sample size to be analyzed due to its lower cost, simpler sample preparation process, and readily available compositional results, it was finally considered as the more appropriate tool for the purpose of extracting geochemical data out of sherds from Hongshan core zone communities.

2.4 Sampling of Hongshan core zone sherds for pXRF analysis

Once pXRF was chosen as the tool for extracting geochemical compositions out of Hongshan pottery, it became clear to us that more sherds could be analyzed and that our sampling strategy should be adjusted accordingly. The first thing we did was to enlarge the sample size from 30 (our original estimate, including 10 Tongxingqi sherds, 10 fine-paste vessel sherds, and 10 coarse-paste vessel sherds) to 50 (10 Tongxingqi sherds, 30 fine-paste vessel sherds, and 10 coarse-paste vessel sherds) per household. This was done to ensure as best as possible sherds of different pastes, types, and vessel forms, as well as for different functional uses, would be sampled to represent the consumption of pottery at each household as well as to reduce the error ranges involved in estimating proportions of different pottery source units represented in each household.

Taking into considerations the research questions we were most interested in and some other topics that were also important and interesting (such as whether different clays were used for making vessels of different types for different functions and uses), 50 sherds were intentionally collected by splitting them into three categories: (1)

Tongxingqi, which refers to non-utilitarian, fine-paste pottery, (2) fine-paste vessel, which refers to finely pasted utilitarian pottery that are typologically or functionally different from Tongxingqi, and (3) coarse-paste vessel, which refers to coarse-paste utilitarian pottery.

Tongxingqi, as it is now widely accepted, were made not for daily use but for ritual and ceremonial activities. The latter two categories were virtually all sherds from utilitarian pottery, although the fine-paste utilitarian vessels were assumed to have been used more often as serving vessels while the coarse-paste one mainly as cooking or storage purpose. The fine-paste utilitarian vessel sherds are the most abundant, compared to the rarer Tongxingqi or coarse-paste vessel sherds, in the sherd pool. Therefore, the random sampling will almost always produce enough fine-paste vessel sherds but very likely not collect Tongxingqi or coarse-paste sherds as many as needed to have their geochemical variations represented in the geochemical study. It is for this particular reason that the stratified sampling was chosen over the random sampling. The stratified sampling and the 10-30-10 scheme make sure that a good, abundant sample of fine-paste utilitarian sherds as well as at least a minimal sample of the rarer Tongxingqi and coarse-paste utilitarian vessels.

Thirty fine-paste sherds could always be found and selected as fine-paste vessel sherds consisted of a very high proportion of sherds collected at each household; in contrast, less than 10 Tongxingqi or 10 coarse-paste sherds were occasionally encountered in some households. Overall, approximately 50 sherds were included in the stratified random sample from each household.

In the original plan, 12 of the 50 households were chosen for sherds to be sampled from: four households from each occupational area (Sanjia, Dongshanzui, and Erbuchi). The 12 households are as follows: (1) households 002, 010, 016, and 022 from the Sanjia area; (2) households 101, 103, 109, 112 from the Dongshanzui area; and (3) households 201, 203, 207 and 208 from the Erbuchi area. Intensive surface collections for these 12 households all yielded large numbers of Hongshan sherds (ranging from 450 to 5,568 sherds), making it more likely that they represent well the variations to be observed in the Hongshan garbage deposited in that location. Besides, they also yielded high proportions of Hongshan sherds, reducing the possibility of chronological confusions. And they were scattered broadly across the occupation zones, thus providing good spatial representation.

Once the stratified sampling strategy was chosen and the sampling process was determined, sherds were selected from the 12 households one occupation area after another. When the pXRF analysis turned out to work faster than previously expected and there still was time available to analyze more sherds, four more household units—two from the Sanjia area (households 017 and 023) and the other two from the Dongshanzui area (households 110 and 116)—were selected following exactly the same standards and sampling procedures described above.

In total, we had a sample of 715 sherds selected from 16 out of the 50 households identified in the upper Daling survey area of Hongshan core zone.

2.5 Experiment for performing pXRF analysis

Before the pXRF analysis was performed on the 27 selected sherds, a series of tests were carried out on those same sherds in the hope of finding out as best as possible the experimental settings most appropriate for collecting pXRF readings from Hongshan sherds. The tests heavily relied on three published works—Goren *et al.* (2011); Hall (2012); Zurfluh *et al.* (2011). The most important things such experimental tests aimed to investigate include: (1) determination of elements potentially useful for geochemical sourcing purpose; (2) the choice of filters (four filters were default equipment with the pXRF analyzer used in this dissertation); (3) the time of collection for recording pXRF readings; (4) the size of x-ray beam spot. Other issues that may influence the collection and interpretation of pXRF readings directly or indirectly were also evaluated, including: (1) the number of readings to be collected from each single sherd; (2) the minimum desired size and shape of sherds in three dimensions (width, length, thickness); (3) the area from which each pXRF reading was preferentially collected; (4) the need for sherds to be cut and polished to produce flat and smoother surfaces; and so forth.

The Niton 950 handheld XRF analyzer we used in this dissertation project is equipped with two modes that could be most useful for extracting geochemical information from pottery/ceramics (Soil and Mining) and four filters for each mode (High, Light, Low, Main). The Soil mode, which uses the Compton Normalization for the purpose of calibration, is usually employed to measure elements of low concentrations (less than 1% or in a ppm-level), and it does not measure light elements such as magnesium (Mg), aluminum (Al), silicon (Si), and phosphorus (P). In contrast, the Mining mode that uses the Fundamental Parameter approach records concentrations for light elements and it is more applied to record elements of higher concentrations. The High, Light, Low, and Main filters are used to fluoresce different ranges of elements (for example, Z=47–56 for the High filter, Z<17 for the Light filter, Z=19–24 for the Low filter, and transition elements for the Main filter).

Standard materials were not used in the pXRF analysis of Hongshan core zone pottery because we believed that as long as the geochemical variations reported by pXRF reveals the same general distribution patterns as other more accurate and reliable techniques (as what has been proved in our pilot studies that compare pXRF results with ICP-AES and benchtop XRF), the pXRF data are acceptable and reliable and no additional standardization is needed.

Some experiments were carried out on the 27 selected Hongshan core zone sherds to test whether or not the goodness of fit to the line (R-square or r^2) would be improved when average concentration of a certain element, which was calculated by pXRF readings increasingly recorded on different areas of the same sherd, was compared to that of the same element recorded by benchtop XRF. This is one of the ways to evaluate the degree of match between pXRF and benchtop XRF data that are believed to be more accurate and reliable. It turned out that the correlation was weak, especially for major elements such as silicon (SiO_2, r^2=0.048) and aluminum (Al_2O_3, r^2=0.186). Compared to major elements, the trace elements produced by pXRF and benchtop XRF show a better correlation, for example, r^2=0.457 for zirconium (Zr), r^2=0.766 for strontium (Sr), and r^2=0.532 for rubidium (Rb). It was therefore determined that the High, Low, and Main filters for the Soil mode can best meet our needs.

The final experimental settings for recording pXRF data can be described as follows: A handheld Niton XL3t 950 GOLDD+ XRF analyzer equipped with a 50 kV x-ray tube (max. 50 kV, 100 μA, 2 W) with an Ag anode target excitation source and a Large Drift Detector

(LDD) with active area of 5 mm^2 fitted with a polymer window (MOXTEK AP 3.3 film), which provides superior x-ray transmission in the low-energy range down to Bee Kα. The x-ray beam spot focused on the sample is about 3 mm in diameter. The detection limits for all analyses were based on a 180-s total analysis time (60 s for the High filter; 60 s for the Low filter; and another 60 s for the Main filter) in the Soil mode.

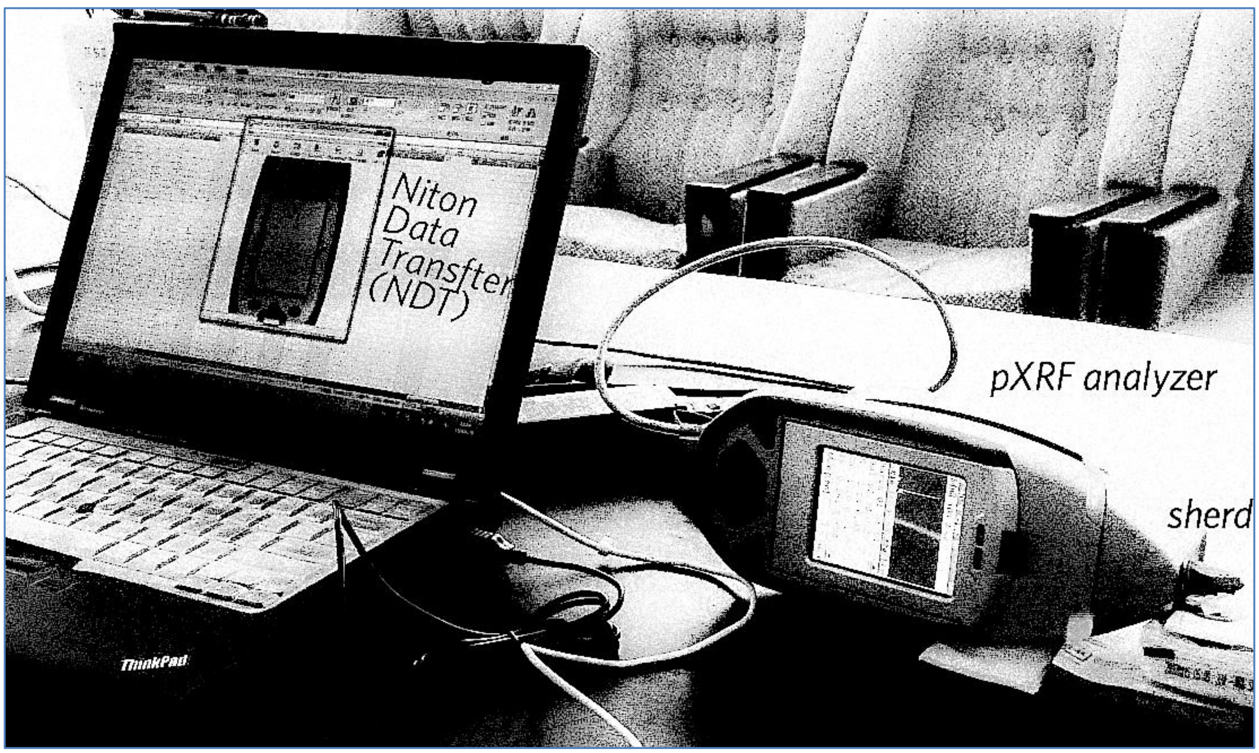

Figure 2.6: Collecting pXRF readings using the Thermo Niton XRF analyzer

3. STATISTICAL ANALYSES OF COMPOSITIONAL DATA

3.1 Preprocessing of pXRF data

The pXRF analysis of the 715 selected Hongshan sherds was carried out in the summer of 2014 at the Niuheliang Workstation, where all sherds collected from the surface collections and stratigraphic tests in the upper Daling regional survey are housed. Each of the 715 selected sherds, as long as it was large or thick enough, was polished by wet sandpapers to produce smooth surfaces on the sherd's cross section and/or, under limited circumstances, on exterior or interior surfaces. Multiple (at least three) pXRF readings were collected at different areas on these smooth surfaces. For each pXRF reading, concentrations of up to 33 elements (Mo, Zr, Sr, U, Rb, Th, Pb, Au, Se, As, Hg, Zn, W, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Sc, Ca, K, S, Ba, Cs, Te, Sb, Sn, Cd, Ag, Pd) were recorded.

Once the pXRF analysis was done on all selected sherds, a geochemical dataset consisting of up to 33 variables (elements) corresponding to more than 2145 cases (pXRF readings) was constructed. To prepare it for further multivariate statistical analysis, this dataset was preprocessed to make sure that: (1) one final pXRF reading was assigned to each investigated sherd to represent the most likely geochemical composition in the vessel that the sherd came from; and (2) only elements whose concentrations were reliably and consistently recorded were retained while others were excluded from further analyses. To do that, it was necessary to compare the three or more pXRF readings collected for each single sherd and look carefully through each of the 33 batches of pXRF readings (corresponding to the 33 detected elements). Decisions were made as to which pXRF readings and what elements seemed to be consistently and reliably recorded and therefore potentially useful for further quantitative data analyses. The main criteria that were adopted for this purpose can be described in order as follows:

(1) If pXRF readings reported missing or undetectable concentrations in <u>too many</u> sherds for certain elements (usually caused

by being too low and/or beyond the limit of detection [LOD] of the pXRF analyzer), these readings as well as elements were excluded from further data analysis. For example, elements such as U, Au, Se, Hg, W, Cu, Co, Sc, S, Cd, Ag, and Pd were quickly excluded by this strategy.

(2) For each single sherd, if its pXRF readings showed dramatic variations (in orders of magnitude) in concentrations of the same elements at the same time, these readings were excluded; if this occurred for a limited number of elements and in only one or two of the sherd's pXRF readings, then the 'abnormally' low or high concentrations for that particular element(s) were replaced by the arithmetic mean of concentrations for the same element recorded in the other pXRF readings for that sherd.

(3) Relative errors were calculated at that point in time for each batch of pXRF readings (or in other words, concentrations of each detected element that seemed potentially usable). This was done by dividing measured concentrations of each detected element by its associated measurement errors (reported by the Niton pXRF analyzer). The results were expressed in percentages. Elements with overall high relative errors (25% and higher) in their pXRF readings were

considered as not suitable for further multivariate statistical analyses and therefore excluded.

Following the procedures described above, eleven elements were finally considered as appropriate and useful for further mathematical calculation and statistical analysis due to their higher consistency and stability in measurements. These eleven elements include major, minor, and trace elements such as Ba (4–5% of relative error), Zr (1–2% of relative error), Sr (1–3% of relative error), Rb (3–4% of relative error), Zn (7–10% of relative error), Ni (5–9.9% of relative error for about 30% of the sherds, 10–19.9% of relative error for approximately 50% of the sherds), Fe (0.4–1% of relative error), Mn (5–10% of relative error), Ti (1–7% of relative error), Ca (1–2% of relative error), and K (1–2% of relative error).

Concentrations of these eleven elements were recorded by pXRF analyzer in two different ways: in units of weight percentage (%) or in units of parts per million (ppm). In addition, some elements (major elements such as Fe and K) have concentrations several orders of magnitude higher than others (trace elements such as Ba and Rb). Therefore, z-score standardization was applied to concentrations of these eleven elements for all 715 sheds, as was done on the 27 sherds in pilot studies (described in detail in section 2.3.4). This process was necessary because it permits concentrations of elements to be compared to each other directly regardless of their units of measurement and prevents elements with generally very high values for their measurements from having a much stronger impact on the results than elements with overall lower measurement values.

3.2 HCA and MDSCAL for data exploratory analysis

Two techniques, hierarchical cluster analysis (HCA) and multi-dimensional scaling analysis (MDSCAL) were applied to the z-scored pXRF datasets. Many studies have confirmed that the combined application of MDSCAL and HCA analyses to the same proximity matrix of similarities promotes clearer pattern recognition and a better understanding of the structure underlying the dataset than either of them would do alone.

The MDSCAL analysis is a tool that aims to conceptualize the similarity (or dissimilarity) observed in a multivariate dataset. Through the MDSCAL analysis, the many variables that quantitatively describe a case (for example, a household, a pottery vessel, or a sherd) are often reduced to two or three variables without losing too much information. Therefore, the MDSCAL results would be a two-dimensional (2D) graph or two-dimensional projections of a three-dimensional (3D) graph, which can be plotted to show the distance (or similarity) among the cases visually.

The HCA analysis can serve the same purpose as the MDSCAL analysis did, especially in the sense that cases would finally fall into different clusters (or groups) based on, for example, how similar or different they were compared to each other on a number of variables. Results from the HCA analysis can be presented by a two-dimensional clustering tree (or a dendrogram), from which one can easily track the clustering process of how each individual case (whether it is a sherd or a household where this sherd came from) was joined to others to form larger clusters as clustering proceeded.

It is hoped that, by applying the HCA and MDSCAL analyses to processed pXRF data, two main purposes can be achieved: (1) revealing the distribution pattern of the 715 selected sherds among the 16 selected Hongshan core zone households. With a much larger sample size now, we would be able to evaluate the robustness of conclusions that were summarized earlier based on the 27 sherds in pilot studies; and (2) investigating the consumption behaviors at the 16 households that yielded these 715 sherds. Once meaningful compositional groups indicating potential production source units are delineated, the degree to which each of the 16 households relied on these production source units can be formulated. This gives us a chance to understand whether inhabitants of the 16 households consumed pottery (or relied on different production source units) similarly or very differently.

The multivariate statistical analysis began with HCA, which was performed in the following order: (1) the full pXRF dataset that contains z-scored concentrations of eleven elements and additional information (such as households from which each sherd was sampled and areas where each household was located) was imported into R, an open-source statistical programming language (URL: https://www.r-project.org, version: 3.2.2); (2) some most popular agglomeration methods and measures of similarity often applied in sourcing studies were tried on z-scored pXRF data, which include: the Complete Linkage on Cosine (or not-centered Pearson) distance measure; the Complete Linkage on

Euclidean distance measure; the Complete Linkage on Pearson Correlation measure; and the Ward method on Squared Euclidean distance measure; and (3) identifying the general patterns on different dendrograms and delineating meaningful clusters or production source units for further data analysis (such as MDSCAL).

The MDSCAL analysis was also completed in R by first making an estimate of the proportion of each identifiable production source unit represented in pottery consumed by each of the 16 households, then measuring the distance between any two of the 16 households in terms of the difference in their ways of pottery consumption. Measurements of distance between any two households were done with Euclidean distance on estimated, non-standardized proportions. Two-dimensional representations of the MDSCAL results were plotted and compared for general and stable patterns that characterized the distribution and consumption of pottery among the 16 Hongshan core zone households.

3.3 Dendrograms and delineation of production source units

3.3.1 General patterns noticed on produced dendrograms

It was not surprising to notice that, when the algorithm method and/or parameter setting changed from one to another, differences showed up in the structures of produced dendrograms, which were caused by changes in the way of each sherd was connected to others to form clusters. However, the general pattern remained relatively stable, as can be most clearly noticed in Figure 3.1, with sherds from households in the Erbuchi area always being clustered more compactly toward one end of the dendrogram and isolated from those from households in the Dongshanzui or Sanjia area while sherds from households in the Dongshanzui or Sanjia area were clustered toward the other end of the dendrogram showing a much higher level of overlapping. These observations were consistent with the observations made on the 27 sherds in the pilot studies, and laid the foundation for delineating production source units.

Closer observations have revealed that, in any of the produced dendrograms, sherds from households at Dongshanzui were usually well mixed with those from households in the Sanjia or Erbuchi area. Again, the distribution of sherds across the dendrograms mimics the spatial relations among Sanjia, Dongshanzui, and Erbuchi (as can be seen clearly in Figure 3.2). More importantly, they revealed potential transfer of pottery within and among different areas. For example, it can be easily noticed that sherds from the same or neighboring households within the same region tended to join together instantly to form clusters when the clustering process started while sherds in other regions were not joined to form larger clusters until the clusters reached higher levels, and that sherds from the same or neighboring households were not always joined into one single (whether large or small) cluster and were often noticed to be mixed with sherds from more distant households (whether in the same region or in different regions). These observations strongly suggested the wide distribution and consumption of pottery made from the same compositional groups or production source units within the same area or among different areas.

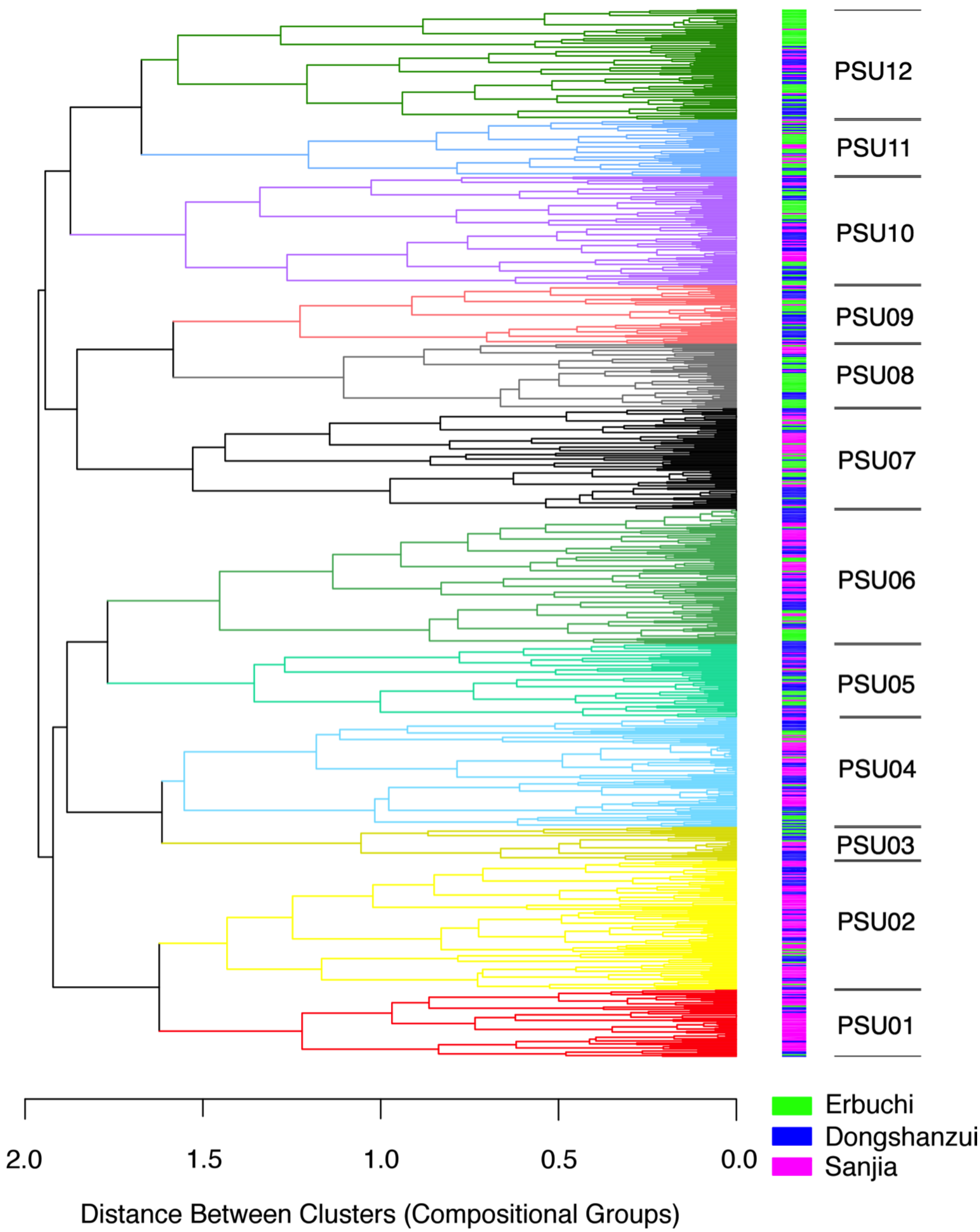

Figure 3.1: Twelve identifiable compositional groups or production source units

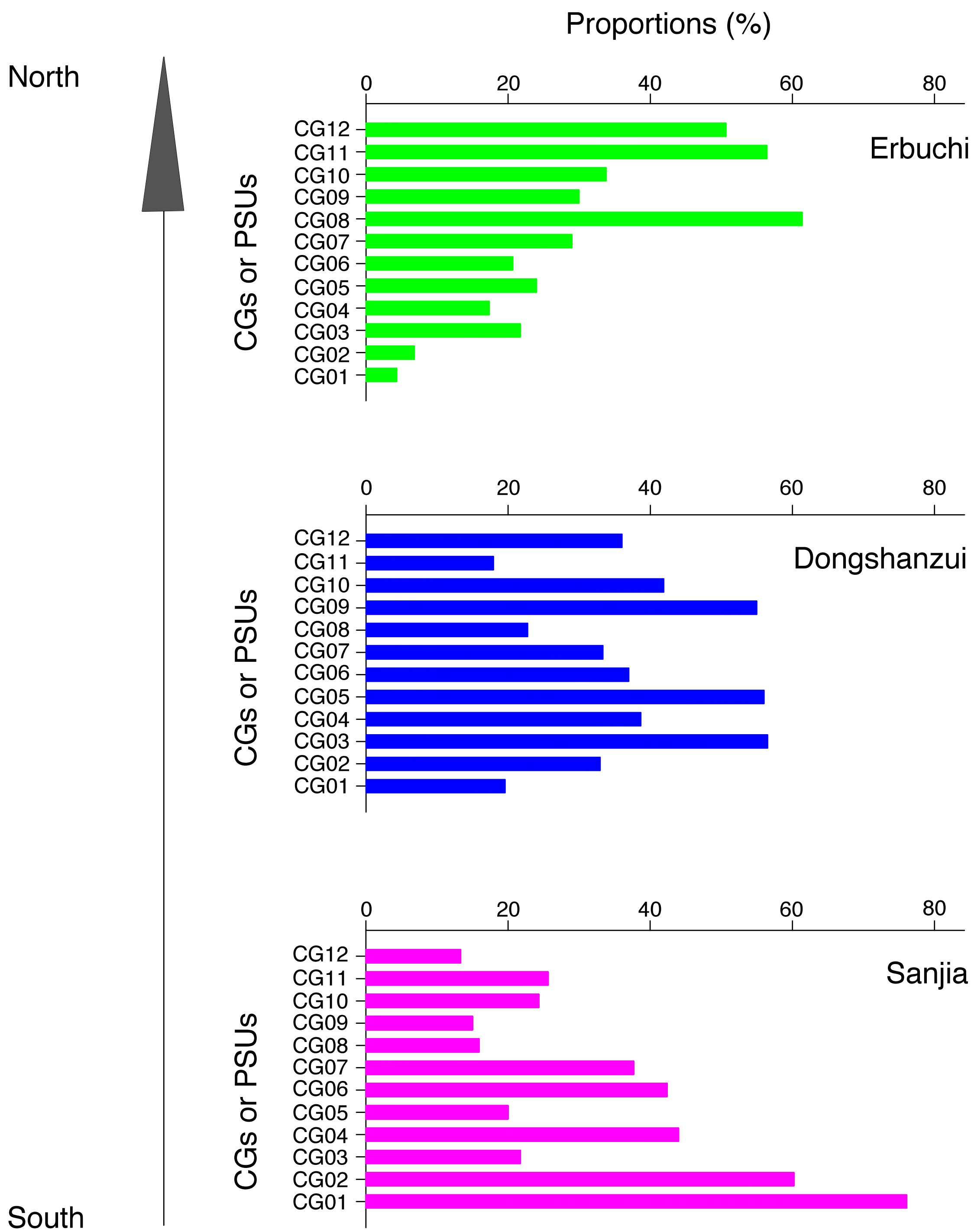

Figure 3.2: Percentage of sherds in the 12 CGs/PSUs in each residential area

3.3.2 Delineation of production source units

It turned out that geochemical variations among the 715 investigated sherds were quite noticeable, which seemed to indicate multiple compositional groups, with each representing a possible different production source unit. Therefore, the delineation of different compositional groups was done on the dendrogram in the hope of recognizing the potential pottery producers (or production source units) these 715 sherds represented. To reduce the arbitrariness and subjectiveness as much as possible, the process of delineating compositional groups on dendrograms was done with the following questions in mind: Which sherds seem to consistently join with which others to form clusters during the clustering process? Do sherds from a certain household tend to be clustered together with those from the neighboring households, and if yes, do the clusters they have formed tend to be placed always in a certain part (for instance, towards one end or right in the middle) of the dendrogram?

It should be pointed out that, even though we followed the aforementioned procedures as closely as possible, the delineation can always be done in several different ways, which produced different numbers of meaningful compositional groups. However, none of them indicates a very few groups (compared to the 16 households) and, no matter how many compositional groups were delineated, the distribution patterns of sherds reflecting pottery consumption behaviors at each household remained highly stable. We reached this conclusion based on some quite extensive data exploration work, such as: looking through the proportional representations (will be discussed in detail in section 3.4) of compositional groups or production source units each household had relied on in their pottery consumption for stable patterns while intentionally modifying the number of delineated compositional groups. To keep our arguments concise and to avoid redundancy in data presentation and interpretation, only the results of the most convincing delineation producing the clearest patterns are presented here. Details about other possible ways of delineating compositional groups on dendrograms and the pottery consumption patterns they generated can be found as complementary data in the University of Pittsburgh Comparative Archaeology Database <www.cadb.pitt.edu>.

Taking the dendrogram (shown in Figure 3.1) produced by the Complete Linkage method and Cosine distance as a similarity measure for an example. Either 5 (Cosine distance = 1.8814), 12 (Cosine distance = 1.5833), 13 (Cosine distance = 1.5698), or 19 (Cosine distance = 1.4317) seems a reasonable number to cut the whole dendrogram into meaningful compositional groups. However, only twelve (12) generates the clearest patterns that group sherds into the most meaningful clusters (compositional groups) and produced the better MDSCAL and HCA results to recognize the intra-household variation. It is this dendrogram and the 12 compositional groups delineated from it that was chosen as the basis for analysis to be discussed below.

3.4 Proportions of PSUs represented at each household

Once the 12 compositional groups were delineated, they suggested to us that 12 production source units quite likely produced the 715 investigated sherds. It also suggested that 12 strongest economic connections existed between the 16 Hongshan households and their pottery providers. If we take sherds in each of the 12 compositional groups as an individual sampling and make estimates of proportions for production source units consumed at each household, we can reveal the production source units different households relied on and measure the intra-household variation in their abilities to establish economic connections with different pottery producers. It is important to be able to say at what level of statistical confidence statements about the proportions of production source units in each household can be made. An 80% confidence level was believed to serve this goal quite well.

As was discussed in section 2.4, the 715 sherds were selected following a stratified sampling strategy and each sherd fell into one of the three categories based on their paste, (possible) vessel form, and function: (1) Tongxingqi sherds, (2) fine-paste utilitarian vessel sherds, and (3) coarse-paste utilitarian vessel sherds. With the 12 compositional groups delineated on the dendrogram shown Figure 3.1, the distribution of 715 sherds across these 12 compositional groups was determined, which allowed for making estimates of the proportions of Tongxingqi, fine-paste, and coarse-paste vessels that were made by the 12 corresponding production source units and consumed at each of the 16 households. If the three paste-form categories were taken as sampling strata, and their individual estimates were pooled, an estimate of the overall proportion of each compositional group in all the pottery of each household could thus be made.

Household D101 can be used as an example to show how the proportional representation of the 12 production source units was estimated for each household. During the upper Daling project, household D101 yielded 96 Tongxingqi sherds, 3518 fine-paste vessel sherds, and 58 coarse-paste vessel sherds in the intensive surface collections. A sample was selected from these sherds consisting of 10 Tongxingqi, 30 fine-paste vessel, and 10 coarse-paste vessel sherds, as described earlier. One of the Tongxingqi sherds, one of the fine-paste vessel sherds, and none of the coarse-paste vessel sherds pertained to production source unit 1 (PSU01). Thus PSU01 is 10% (1/10) of the Tongxingqi sample, and this 10% is the best estimate of the proportion of Tongxingqi sherds at D101 that pertain to PSU01. Following the same logic, PSU01 is 3.3% (1/30) of the fine-paste vessel sample and 0% (0/10) of the coarse-paste vessel sample. A standard error ($\boldsymbol{SE}$) can be assigned to each estimated proportion as well by the following equation:

$$\boldsymbol{SE} = \sqrt{\frac{\boldsymbol{p(1-p)}}{\boldsymbol{n}}}$$

where $\boldsymbol{SE}$ is the standard error of the estimated proportion for a given household, production source unit, and paste-form category; $\boldsymbol{p}$ is that estimated proportion; and $\boldsymbol{n}$ is the number in the sample for that paste-form category (usually 10 for Tongxingqi or coarse-paste vessel sherds and 30 for fine-paste vessel sherds). Since one standard error represents a confidence level of about 67%, it is then estimated (at about 67% confidence level) that 10% ± 9.5% of the Tongxingqi vessel sherds, 3.3%±3.1% of the fine-paste vessel sherds, and none (0%) of the fine-paste vessel sherds at D101 were produced by production source unit 1 (PSU01), even though the standard error of 0 does not mean certainty that there were no fine-paste sherds at this household pertaining to this particular production source unit.

The proportion of sherds from a given production source unit among all the sherds from a household can be estimated by pooling the estimates for the three paste-form categories:

$$\boldsymbol{p} = \frac{\boldsymbol{N_t p_t + N_f p_f + N_c p_c}}{\boldsymbol{N}}$$

where $\boldsymbol{p}$ is the proportion of a given production source unit among all the sherds from a household; $\boldsymbol{N_t}$, $\boldsymbol{N_f}$ and $\boldsymbol{N_c}$ is the total number of Tongxingqi, fine-paste, and coarse-paste vessel sherds recovered from the household, respectively; $\boldsymbol{p_t}$, $\boldsymbol{p_f}$, and $\boldsymbol{p_c}$ is the estimated proportion of Tongxingqi, fine-paste, and coarse-paste vessel sherds from the household that pertain to the given production source unit; and $\boldsymbol{N}$ is the total number of sherds recovered from the household. Therefore,

$$\boldsymbol{p_{PUS01}} = \frac{\mathbf{96 \times 0.1 + 3518 \times 0.033 + 58 \times 0}}{\mathbf{3672}} = \mathbf{0.034}$$

which means that the best estimate of the proportion of sherds at household D101 made from PSU 01 is 3.4% (0.034). In addition, a pooled standard error ($\boldsymbol{SE}$) can be calculated by the following equation:

$$\boldsymbol{SE} = \frac{\sqrt{\boldsymbol{N_t^2 \times SE_t^2 + N_f^2 \times SE_f^2 + N_c^2 \times SE_c^2}}}{\boldsymbol{N}}$$

For PSU01,

$$\boldsymbol{SE_{PUS01}} = \frac{\sqrt{\mathbf{96^2 \times 0.095^2 + 3518^2 \times 0.031^2 + 58^2 \times 0^2}}}{\mathbf{3672}} = \mathbf{0.032}$$

To get the error range at 80% confidence level (which is what is used in this dissertation), the value of $\boldsymbol{SE}$ should be multiplied by the value of $\boldsymbol{t}$ corresponding to 80% confidence level and 49 (=50-1) degrees of freedom. As $\boldsymbol{t}$ is approximately 1.296, then we have $\mathbf{1.296} \times \boldsymbol{SE_{PSU01}} \approx \mathbf{0.041}$.

Finally, it can be said that the proportion of the sherds in household D101 that were made by production source unit 1 (PSU01) is 3.4%±4.1%, at an 80% confidence level.

Table 3.1: Proportions of PSUs represented at each household

Production Source Units (PSUs)	**Sanjia**						**Dongshanzui**						**Erbuchi**			
	Mean proportions (%) of pottery made from different PSUs in pottery consumed at each household															
	S002	**S010**	**S016**	**S017**	**S022**	**S023**	**D101**	**D103**	**D109**	**D110**	**D112**	**D116**	**E201**	**E208**	**E207**	**E203**
PSU01	15	0	7	33	12	25	3	2	3	7	0	4	3	0	2	0
PSU02	33	18	24	7	27	22	14	1	8	14	25	13	1	2	3	5
PSU03	3	3	0	0	0	0	0	12	2	0	12	0	0	2	3	4
PSU04	10	21	28	18	11	0	17	4	16	7	18	0	5	4	3	2
PSU05	3	12	0	0	0	4	13	7	2	27	13	18	7	10	4	4
PSU06	17	14	6	26	8	14	29	14	33	7	6	4	22	9	2	9
PSU07	10	17	16	4	20	3	13	12	14	0	0	7	23	8	6	10
PSU08	0	3	3	0	0	10	3	0	3	7	0	7	15	18	8	16
PSU09	3	0	3	0	0	1	4	14	0	7	18	18	1	2	13	8
PSU10	4	5	10	0	19	7	0	19	16	1	2	6	1	15	10	20
PSU11	0	3	1	4	0	0	0	0	0	3	6	1	2	10	14	11
PSU12	0	5	0	7	0	14	3	14	3	21	0	23	22	19	32	11
Total (%)	98	101	98	99	97	100	99	99	100	101	100	101	102	99	100	100

Following the mathematical calculations described above, proportions of the sherds recovered from each of the 16 households that were produced by the 12 production source units can be estimated; these were shown in Table 3.1. In addition, an error range was also calculated and assigned to each estimated mean proportion (although they were omitted from Table 3.1). These proportions of production source units (PSUs) in different households will become central to the discussion in Chapter 5 which answers the research questions originally posed.

3.5 Summary

There are many possible ways to make use of the compositional information extracted from Hongshan pottery by the pXRF analyzer for pattern recognition. In this chapter, we chose hierarchical cluster analysis as the very fundamental tool to build clustering trees and characterize clusters based on the similarity in sherds' geochemical compositions. Twelve compositional groups were identifiable on the dendrogram with the clearest structures, and they were believed to indicate 12 different production source units (or 12 possible pottery producers). Based on these 12 delineated compositional groups, we made estimates of the proportions of different PSUs represented in the pottery consumed at each household. These 12 production source units and their proportional representations in the 16 selected Hongshan households will be the foundation that discussions in Chapter 5 most heavily rely on.

4. MINERAL PHASE ANALYSIS: A COMPLEMENTARY STUDY

4.1 The importance of mineralogical data

Geochemical or compositional data of pottery and its raw materials have been proven by many case studies (including the present work) to be extremely useful for constructing regional geochemical baseline and understanding intra- and inter-regional geochemical variability. Elements with characteristic fingerprints and variations in their concentrations recorded by investigative and analytical tools altogether help describe the geochemical characteristics of pottery raw materials (clays; mineral inclusions in the silt, sand, temper; etc.), which lay the very foundation for differentiating or locating pottery raw material sources exploited by ancient potters. However, it was realized almost immediately, after the increasing applications of analytical approaches and instruments to geochemical sourcing studies in 1970s, that geochemical compositions alone did not always suffice to claim geochemical variability and identify compositional groups.

As Peacock (1970) rightly pointed out in a review article on scientific analysis of ancient ceramics, chemical analysis demonstrates the presence/absence of elements in the investigated samples and shows the variations in geochemical compositions of detected elements. It, however, does not explain where elements come from or what minerals they belong to. Such information could be equally important for relating certain clays to a geographic location or region. One example that has demonstrated the importance of mineral phase identification to geochemical sourcing studies is the clay-mineral provinces established for the Southeastern United States. Even though the entire Southeastern region seemed to be dominated by some common clay minerals (such as montmorillonite, kaolinite, illite, and chlorite), different combinations or proportions of these minerals were noticed to characterize different parts of the Southeastern region: montmorillonite tends to dominate in the west while kaolinite in the east; in contrast, illite and chlorite are more common in the north and south, respectively (Steponaitis et al. 1996). This study, by combining the geochemical and mineralogical data, convincingly demonstrated that some pottery specimens were nonlocal products; in addition, it even assigned these specimens to known geographical locations.

4.2 Obtaining mineralogical information

Probably the most convenient way to gather mineralogical information from pottery/ceramics and their raw materials is through the modern instrumental techniques and methods such as X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and Raman spectroscopy. These different analytical approaches have different working principles, specific or no requirements for sample preparation, and simple to complex procedures for data collection and interpretation. However, they all aim to confirm the presence of certain minerals in the analyzed samples by recording their unique chemical structures at the molecular/atomic level. It is also important to keep in mind that, hypothetically speaking, these equipment can only confirm, rather than exclude, the presence of a certain mineral as they all have a detection limit (DL) issue. That is to say, if a certain mineral exists in the analyzed sample in a quantity that is too low to be analyzed by the equipment, it will not be detected and reported.

It is the powder or polycrystalline X-ray diffraction (PXRD) analysis that this dissertation will use to extract the mineralogical compositions out of the selected Hongshan core zone sherds. The PXRD analysis was chosen because: (1) it is a long-established methodology and an exceptionally powerful and accurate tool for mineral phase identification; (2) the minimal sample size for the preparation of ground power often is a few tenths of grams, which basically causes no visible damage to materials such as pottery and ceramics; (3) data interpretation is quite straightforward as a reference library consisting of crystal structure data of over 140,000 inorganic compounds is available for the search/match purpose on many XRD units; and last but not the least (4) it allows for a semi-quantitative determination of each identified phase. Therefore, the <u>mineralogical composition</u> presented here is actually a <u>proportional representation</u> indicating the relative abundance of all identifiable minerals in each powdered, homogenous sherd specimen.

More details about fundamentals of X rays, history of powder X-ray diffraction, advantages and limitations of PXRD, sample preparation, collection and processing of X-ray diffraction patterns, and the process of identifying an unknown powered sample with mixed crystalline materials or of quantifying the identifiable mineral phases using the Rietveld refinement method can be found in the following books: Fultz and Howe (2013:1-58); HUANG Jiwu 黃繼武 and LI Zhou 李周 (2012); Waseda et al. (2011:21-127); Will (2006); Young (1993).

4.3 Purpose of applying PXRD to Hongshan sherds

The mineralogical data collected by PXRD analysis in this chapter aims to provide additional information to advance the current understanding of (or observations made on) geochemical (pXRF) data described in Chapter 3. More specifically, it will try to demonstrate whether or not the patterns noticed for geochemical variations across the three areas (Sanjia, Dongshanzui, and Erbuchi) persist in the mineralogical data. For example, it would help to determine: (1) What mineralogical compositions seem to, in a general sense, characterize the pottery raw materials exploited most often by the Hongshan core zone potters? (2)

Whether or not pottery produced by the 12 production source units shows mineralogical differences as it did geochemically? (3) How does pottery consumed in one of the three residential areas compare to that in the other two in terms of their different kinds and quantities of minerals; and (4) Does the mineralogical difference/similarity seen in the pottery to correlate with different vessel forms or pastes?

4.4 Selection and preparation of 171 sherds for PXRD analysis

The purpose of proposing a semi-quantitative XRD analysis is to complement the (pXRF) compositional results with mineralogical information. It is not simply a comparison or connection between elements (pXRF data) and mineral phases (XRD data) to explain which elements may have come from (or been contributed by) what minerals. The primary focus here is to test whether or not the 12 production source units delineated by multivariate statistical analysis of pXRF data seem replicable in mineralogical data, and if yes, how well the mineralogical compositions correspond to characterize each delineated production source unit. That being said, we would like to know if there is a coherent, stronger mineralogical similarity underlying the sherds that fell into the same delineated production source unit.

For the reason elaborated above, specimens for semi-quantitative powder X-ray diffraction analysis were selected based on a dendrogram that reveals the geochemical similarity and suggests for production source units among the 715 Hongshan core zone sherds. Considering the cost of money and time, one out of every four sherds was selected in each cluster of sherds from the top to the bottom of that dendrogram.

The sample size finally reached 171. In Figure 4.1, the selected 171 sherds (marked in red, narrow bars) are placed along the right side of the dendrogram with 12 delineated production source units. It can be clearly seen that they are quite spread out across the dendrogram. Figure 4.2 compares the percentage of sherds in each of the 12 production source units with that of sherds selected from the same production source units for PXRD analysis. The percentages are quite close (with a difference of 2–3% for production source units 1, 2, and 7, and 0–1% for the other ones). Therefore, the 171 sherds can be seen as representative of the mineralogical features that characterized the 715 sherds.

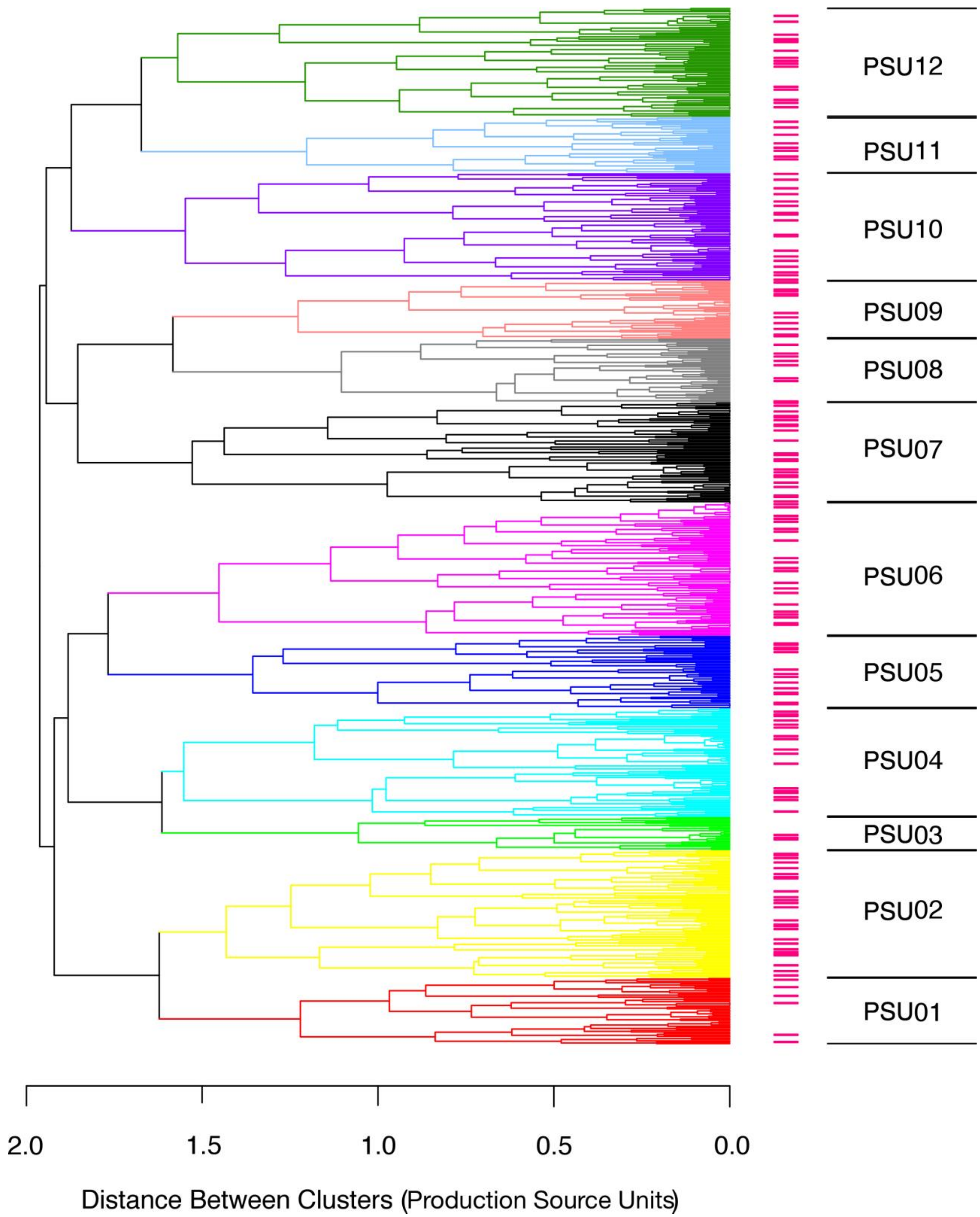

Figure 4.1: Distribution of the 171 sherd samples in the 12 PSUs

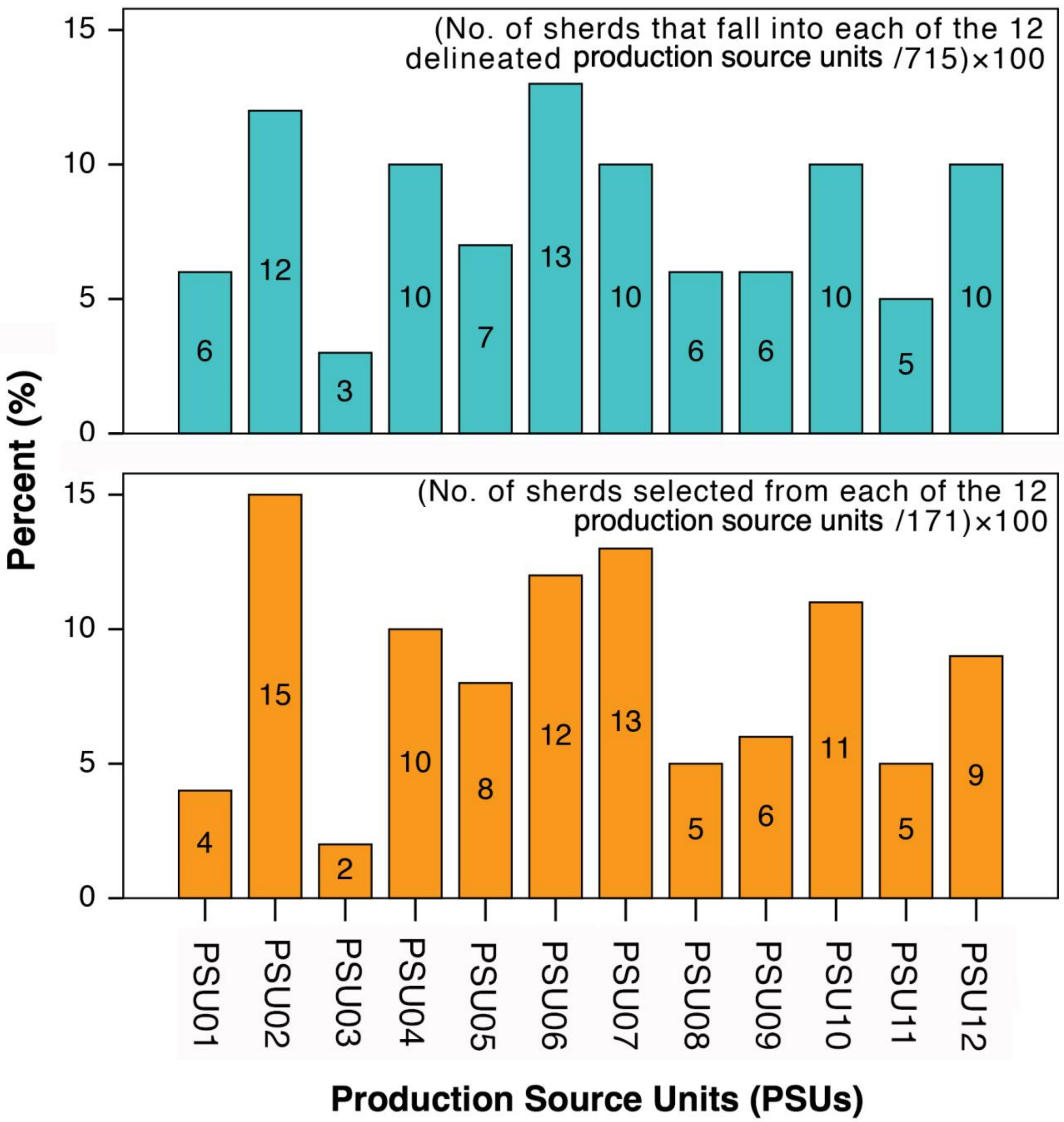

Figure 4.2: PSU distribution (all 715 samples vs. 171 samples used in XRD)

Among the 171 selected sherds, 169 belong to the Hongshan period and 2 to the Xiaoheyan period. Sixty-seven (67) of the 171 sherds can be identified by vessel forms, including 45 non-utilitarian vessels (44 Tongxingqi and one incense burner) and 22 utilitarian ones (13 Guan, 5 Bo, 3 Pen, and one Weng). In regard to the paste, 57 fine-paste (including 44 Tongxingqi and 13 fine-paste vessel sherds) and 10 coarse-paste sherds whose vessel forms are identifiable are included in the 171 selected sherds.

Each of the 171 sherds was photographed before a small specimen was removed from it. The sampling process was done with a scalpel, with which a small specimen (weighted to a few hundred micrograms) was removed from the sherd's smooth cross-section where pXRF readings were collected earlier. The specimen was supposed to represent the mineralogical characteristics of each sherd. Therefore, it was sampled not from the top surfaces but from the inner part of the cross-section, in the hope of avoiding or reducing the influence of dramatic mineral phase transition and transformation due to high temperature in the firing process.

The preparation of sherd specimens into homogenized, finely ground powder samples and the X-ray diffraction analysis were carried out in the Key Laboratory of Non-Ferrous Metal Material Sciences and Engineering, School of Materials Science and Engineering, Central South University (Changsha, China). A Rigaku (Tokyo, Japan) D/Max-2500 X-ray diffractometer was used to record diffraction patterns. The working conditions and instrumental parameters of X-ray diffractometer, which remained the same for all the 171 samples, can be found in the final report of semi-quantitative XRD result for each sherd (see Figure 4.3 for an example, which shows step-scanning measurements of PXRD pattern, identified phases, and proportion of each phase estimated by the Rietveld refinement method). Data processing and interpretation was done with the MDI (Materials Data Incorporation, USA) Jade XRD software package. Each obtained XRD pattern was subject to a qualitative analysis at first to determine the kinds of mineral phases detectable in each sherd specimen, and then to the Whole-Pattern-Fitting/Rietveld Refinement Function for quantitative analysis.

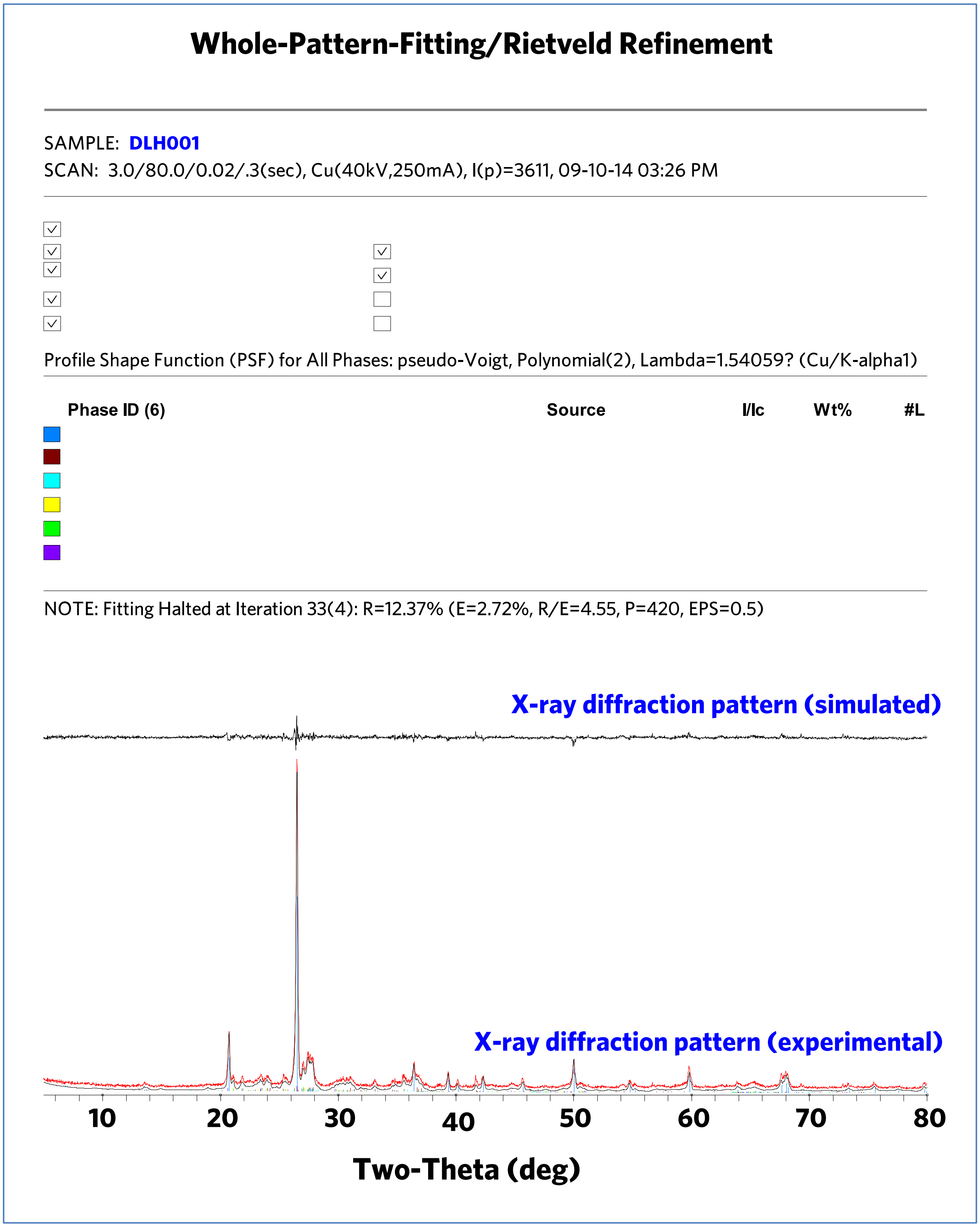

Figure 4.3: A final report of PXRD analysis

4.5 Results and Discussion

4.5.1 Identified minerals in the 171 tested sherds

In pottery analysis, pottery fabrics are considered as mainly consisting of two components: plastic clay matrix (70–80, wt%) and non-plastic inclusions (20–30, wt%). A clay matrix is composed of clay minerals smaller than 0.02 mm (20 μm), which often are not visible to naked eyes and can only be seen and studied with the assistance of microscopes. Inclusions, on the other hand, are mostly present in the form of minerals with larger particles that are noticeable by direct observation with naked eyes (Orton and Hughes 2013:71). Mineral inclusions could occur naturally in the clay sources and be retained in the final pottery/ceramic products, with or without phase transformation during the firing process. Or, they could be intentionally selected by potters and added into the clay to achieve some particular physical properties. Sometimes, separating the clay matrix and mineral inclusions for parallel phase identification is important for understanding the pottery making technology as the potters may have produced pottery using clays and mineral inclusions from two different geological sources.

In the PXRD analysis, each specimen of the 171 selected Hongshan core zone sherds was ground into fine and well-homogenized powder. No effort was made to separate the clay matrix and mineral inclusions for two main reasons: (1) many of the selected Hongshan sherds (almost all Tongxingqi and a good many fine-paste vessel sherds) were very finely made and contain very tiny mineral inclusions. Larger inclusions do exist but only occur in very low frequency and small quantities, suggesting that they probably are naturally occurring, rather than intentionally added, in the clay that was used to make into this pottery; and (2) some fine-paste and all coarse-paste sherds do contain mineral inclusions a lot larger and more noticeable. Considering their utilitarian nature and the small spatial scale they were distributed across, it is hard to imagine that Hongshan potters chose these minerals quite distant from the locations where clay sources were exploited, and even if they did, minerals as inclusions should still very likely be indistinguishable from the clay sources in terms of their mineralogical compositions. Moreover, time and money are two other concerns that prevent the separation of clay matrix and mineral inclusions for parallel phase identification.

For the reasons described above, the final PXRD results revealed actually the mineralogical compositions of both clay matrix and mineral inclusions present in each tested sherd. The qualitative phase identification has reported a total of 16 minerals in the 171 Hongshan core zone sherds. These minerals are (see Table 4.1): (1) quartz, (2) albite, (3) anorthite, (4) orthoclase, (5) microcline, (6) muscovite, (7) hematite, (8) spinel, (9) kyanite, (10) sanidine, (11) phlogopite, (12) oligoclase, (13) tremolite, (14) halloysite, (15) cordierite, and (16) magnesium dialuminium trisilicate. Particles of these sixteen minerals are believed to exist, individually or in aggregate, in the analyzed pottery as clay matrix and/or mineral inclusions.

The last six minerals (phlogopite, oligoclase, tremolite, halloysite, cordierite, and magnesium dialuminium trisilicate) are believed to have resulted from unintentional introductions, considering their extremely low frequency, random occurrence (showing no preference to paste, vessel form, or area), and low abundance in tested sherds. On the other hand, the first ten minerals are more constant and stable components, whether their occurrences were due to the intentional or unintentional actions.

Table 4.1: The 16 mineral phases identified in the 171 sherd specimens

	Identified phases	Chemical formula	Frequency (Counts/Percents)		
			Sanjia (total: 66)	Dongshanzui (total: 60)	Erbuchi (total: 45)
1	*Quartz*	SiO_2	66(100%)	60(100%)	45(100%)
2	*Albite*	$Na(AlSi_3O_8)$	65(98.5%)	59(98.3%)	45(100%)
3	*Anorthite*	$Ca(Al_2Si_2O_8)$	66(100%)	57(95.0%)	45(100%)
4	*Orthoclase*	KSi_3AlO_8	34(51.5%)	34(56.7%)	31(68.9%)
5	*Microcline*	$K(AlSi_3O_8)$	66(100%)	60(100%)	44(97.8%)
6	*Muscovite*	$KAl2((AlSi_3)O_{10})(OH)_2$	35(53%)	37(61.7%)	29(64.44%)
7	*Hematite*	Fe_2O_3	43(65.2%)	46(76.7%)	33(73.3%)
8	*Spinel*	$(Mg_{0.588}Fe_{0.188}Al_{0.224})(Mg_{0.227}Al_{1.766}Fe_{0.007})O_4$	19(28.8%)	17(28.3%)	12(26.7%)
9	*Kyanite*	$Al_2(SiO_4)O$	20(30.3%)	21(35.0%)	11(24.4%)
10	*Sanidine*	$KAlSi_3O_8$	12(18.2%)	10(16.7%)	4(8.9%)
11	*Phlogopite*	$K(Mg_{2.18}Fe_{0.82})(Al_{1.29}Si_{2.71}O_{10}((OH)_{1.82}F_{0.18}))$	0	1(1.6%)	1(2.2%)
12	*Oligoclase*	$(Na,Ca)(Si,Al)_4O_8$	0	1(1.6%)	0
13	*Tremolite*	$Ca_2Mg_5(OH)_2(Si_8O_{22})$	0	1(1.6%)	0
14	*Halloysite*	$Al_2Si_2O_3(OH)_8$	1(1.5%)	1(1.6%)	0
15	*Cordierite*	$Mg_2Al_4Si_5O_{18}(H_2O)_{0.75}$	1(1.5%)	1(1.6%)	0
16	*Magnesium Dialuminium Trisilicate*	$(MgAl_2Si_3O_{10})_6$	0	1(1.6%)	1(2.2%)

By summarizing the phase identification results, it can be said that quartz (the most important and common inclusion), feldspars (albite, anorthite, microcline, orthoclase), mica (muscovite and phlogopite), ferrous (hematite) and spinel-rich materials, most likely explain the general mineralogical compositions of clays and/or inclusions in the Hongshan core zone pottery.

4.5.2 Mineralogical variations among the 12 PSUs

One of the purposes for PXRD analysis to have been carried out on sherds selected from the 12 PSUs and supposedly representative of each PSU's mineralogical characteristics is to test whether or not featured mineralogical compositions also characterize the same 12 PSUs, just as geochemical compositions did. With the proportional representation of mineralogical composition (consisting of the ten major minerals) of sherds that fell into each of the 12 PSUs, a series of statistical analyses were carried out to look for patterns in mineralogical compositions. For example, hierarchical cluster analysis and multi-dimensional scaling analysis were applied to explore the mineralogical compositions' similarity and dissimilarity between sherds from different areas, of different pastes, and with different vessel forms.

It turned out that all the 171 sherds were just randomly distributed and well mixed with each other however their mineralogical compositions were measured for similarity or dissimilarity. None of the 12 PSUs has mineral(s) or a combination of minerals that seems unique enough (in kinds or in quantities) to characterize one particular PSU or several PSUs. This result, upon closer consideration, is not surprising given the fact that minerals (such as quartz, microcline, albite, anorthite, and orthoclase) occurred in the 171 sherds at very high frequency are also in high abundance, which would have resulted in unanimously high weights for the similarity measure.

In a word, it seems that the 12 production source units delineated by geochemical data are not replicated by mineralogical data. This leads us to assume that there is no significant mineralogical difference among the 715 sherds that are represented by the 171 selected sherds. Alternatively, we can say that these 171 Hongshan sherds seemed to be made from raw materials with quite a "homogenous" mineralogical composition. [Results of hierarchical cluster analysis and multidimensional scaling analysis of the mineralogical compositions were omitted here, but they are available in the University of Pittsburgh Comparative Archaeology Database < www.cadb.pitt.edu>.]

4.5.3 Mineraological difference among sherds or areas

Figure 4.4 is a graphic representation of the frequency of occurrence of the first ten minerals in the 171 selected sherds. Quartz, albite, anorthite, and microcline are detected in almost each and every sherd, suggesting that they are the most common mineralogical compositions of clays and/or minerals in clays and/or minerals used to make into all these 171 Hongshan core zone sherds. Less frequently seen minerals include orthoclase, muscovite, and hematite, which occur in 50-80% of the tested sherds. Still less are kyanite, spinel, and sanidine, which are detected in less than 40% of the tested sherds.

Statistical analyses carried out on the proportional mineralogical compositions for the three groups of sherds (Tongxingqi, fine-paste, or coarse-paste vessel sherds) or sherds from the three areas in the hope of distinguishing them failed to reveal meaningful patterns. The results showed that variations in contents of the ten minerals do exist among different groups of sherds or sherds from the three areas, but generally speaking, they are not significant enough to make one group or one area stand out against the other groups or areas mineralogically. This finding has two important implications: (1) the three groups of sherds are mineralogically indistinguishable from each other; and (2) sherds from the three areas are mineralogically indistinguishable from each other. There are two possible explanations for such an observation: either all (both non-utilitarian and utilitarian) pottery consumed in the three areas was produced by the same group of potters following the same standards (raw materials, techniques, recipes, procedures, etc.) or it was all prepared from raw materials (clays and minerals) that came from several different geographical locations but all fell into the same or similar geological and/or mineralogical backgrounds.

The pXRF results, however, have clearly suggested pottery production activities in each of the three areas, as indicated by geochemical variations among sherds from the three areas. Therefore, it seems that the former possibility can be excluded. It seems more likely that different pottery production activities were conducted in each of the three areas using geochemically different but mineralogically indistinguishable pottery raw materials. Such a finding supports the assumption that the mineralogical background for the region where these three areas are located seems somewhat 'homogenous' (as indicated in section 4.5.2).

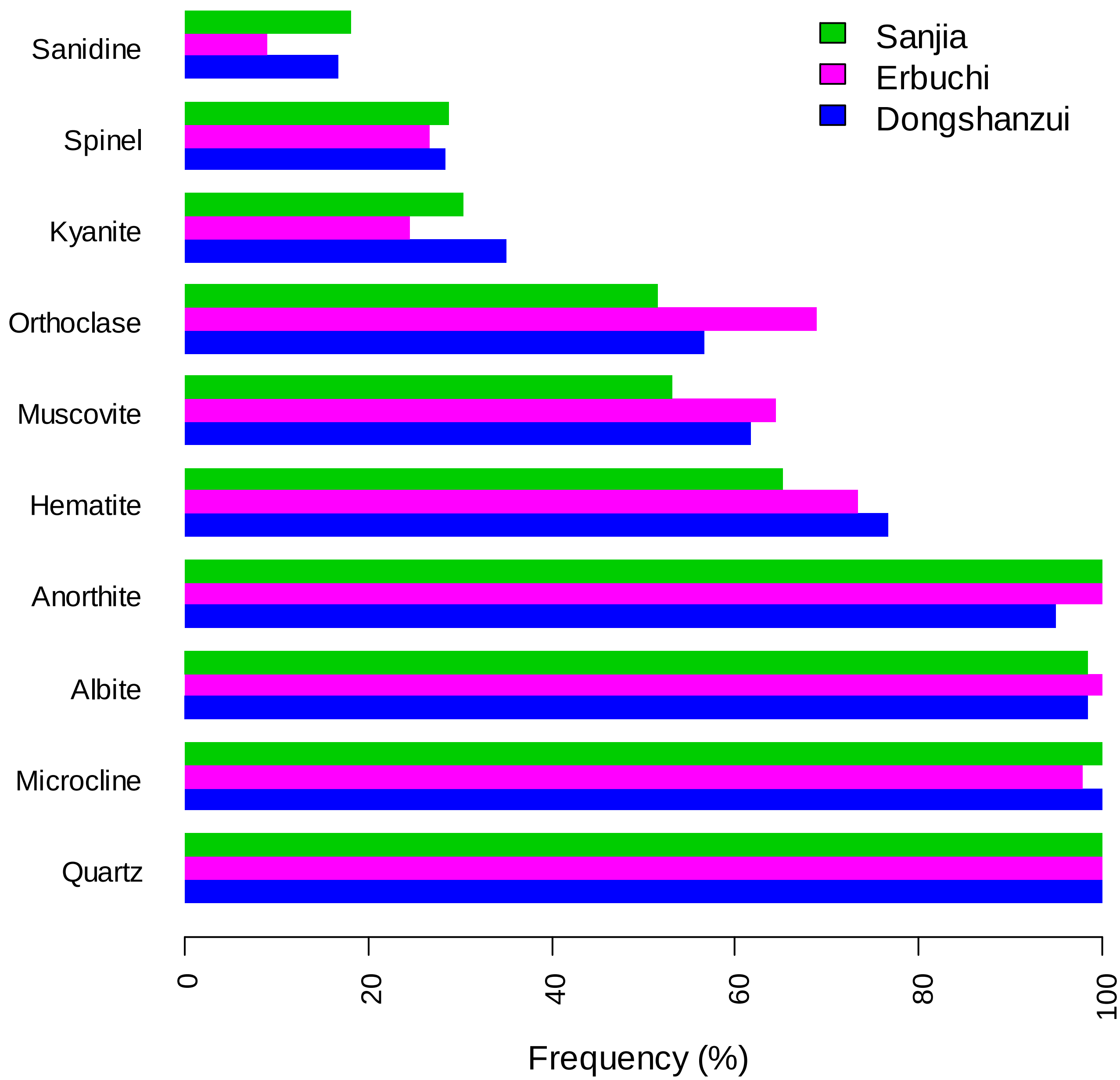

Figure 4.4: Percentage presence of the ten major minerals in the 171 sherds

4.6 Summary

The PXRD analysis of 171 selected Hongshan core zone sherds failed to replicate the groupings of sherds revealed by pXRF data: sherds that fell into the 12 production source units do show some variations in their mineralogical compositions, but such variations cannot be quantitatively demonstrated as the geochemical variations. Even the 171 sherds, if considered as a full sampling pool, do not suggest any patterned, noticeable mineralogical variations among the three areas. Similar conclusions are also applicable to pottery made into different vessel forms or with different pastes.

Mineraologically, pottery raw materials (such as clays and inorganic inclusions) are complex mixture of different minerals that all finally came from weathering rocks (Orton and Hughes 2013:121-125). Therefore, the mineralogical composition of pottery raw materials is strongly dependent on their parent materials (weathering rocks). The investigated Homngshan core zone pottery, as suggested by X-ray diffraction analysis, shared a lot of minerals in common: quartz and feldspars being the most common and abundant minerals and less commonly mica, ferrous (hematite) and spinel-rich substances. All these features agrees well with the mineraological compositions of the locally obtainable rocks (sandstone, conglomerate, andesite, volcanic rock fragments, etc.), weathering rocks, and soils (Quaternary loess or loess-like soils) in low mountians, rolling hills, and flat valley floors where the Hongshan households were most often located and Hongshan pottery was distributed (WU Guangju 乌广聚 1991:139-140). Hypothetically speaking, the Hongshan people residing within the Sanjia, Dongshanzui, and Erbuchi areas can make pottery almost anywhere near their residential sites using clays and other raw materials. The mineralogical data did not show any significant difference among sherds collected from the three areas. Such an observation, in addition to being seen as a reflection of weak regional mineralogical variations, can also be considered as supporting evidence for local pottery production.

5. UNDERSTANDING ECONOMIC DIFFERENTIATION THROUGH POTTERY PROCUREMENT

5.1 Response to Research Question 1

RQ1: Did each of the 16 selected Hongshan households make its own pottery?

The short answer to this question is No. Firstly, if inhabitants of each of the 16 selected Hongshan households procured pottery raw materials themselves and made pottery for their own use, there would have been <u>approximately</u> 16 compositional groups or production source units (PSUs) recognizable, when the 715 sampled sherds representing the pottery consumed at the 16 households formed clusters based on their geochemical similarities/dissimilarities. This is because inhabitants of each Hongshan household would have relied heavily on resources that were easily obtainable and suitable for pottery-making, and customarily procured raw materials from loci that were quite close to their occupation sites and may or may not be accessed by their neighbors. Such a pattern of raw materials procurement, along with the different practices for raw materials processing and pottery-making traditions conducted within different households, would have generated greater geochemical variations between pottery produced and consumed at different households and therefore allowed more compositional groups or PSUs to be identifiable. It is termed as "approximately 16" because two households adjacent to each other may have procured raw materials from the same loci or treated pottery raw materials in the same way (for example, same recipes and techniques), which made it difficult to distinguish their pottery geochemically. Therefore, the total number of identifiable PSUs would be reduced slightly, but it should still be close to, rather than a lot less than, 16.

Secondly, if every household made their own pottery, there would have been one PSU (or sometimes two PSUs) dominating the pottery consumed at each household. If each household procured, whether consciously or subconsciously, raw materials mainly from one or a very few loci close to where the household was located and made use of them for pottery production, the pottery they made and consumed would have been quite likely geochemically or compositionally homogenous. Therefore, there would have been a good chance that all pottery made and consumed within each household corresponded to one or two common PSUs and different households had their own highly distinctive and dominating PSUs. If this truly happened, we would expect to see that the selected 50 or so sherds representing pottery consumed at each of the 16 households were clustered closely to indicate a single, common PSU.

Thirdly, if each household made their own pottery, there would have been fewer commonly shared PSUs between different households and especially between different areas. If each household made their own pottery, there would have been little or no motivation for pottery to transfer between different households even within the same area, let alone to cross the geographical boundaries of the three areas. Thus, households within one area would have demonstrated a very strong focus on their own PSUs (that is, a number of PSUs that were mainly or only seen in that particular area and rarely or not seen in the other two areas) and barely consumed PSUs typically seen in the other two areas.

However, the evidence we have seen on the 715 Hongshan sherds did not support the hypothesis that every household made their own pottery. The reasons can be listed as below: (1) Only 12 meaningful PSUs were recognizable for the 16 Hongshan households. This suggests less geochemical variations (or in other words, more common PSUs) than expected for pottery consumed by the 16 households if each of them actually made pottery for their own use; (2) The pottery consumed at each of the 16 households indicated the presence of multiple, rather than one or two, PSUs. This suggests a greater geochemical complexity for the pottery consumed at each household, because apparently no household possessed pottery made from only one or two PSUs unique to that particular household or area; (3) While it seems true that each household consumed pottery made from multiple PSUs, it is also true that the pottery sampled from the same household often failed to indicate a shared PSU that dominates the pottery seen at that household. Almost all the households consumed pottery made from a few PSUs at a relatively high level (in terms of the proportional representation of identifiable PSUs in each household); and (4) The 12 identifiable PSUs are shared not only between households within the same area, but also across the geographical boundaries of the three areas. For example, PSU12 characterizes the pottery consumed in the Erbuchi area, but it is also noticed for pottery consumed in the Sanjia and Dongshanzui areas in some small quantities. This suggests that pottery made from the 12 PSUs was not restricted to a certain household or residential area; rather, it was quite extensively distributed across different households and areas, suggesting a fairly open, rather than closed, pottery network.

Concluding remarks: It does not seem likely that each of the 16 Hongshan households made pottery for their daily use. The smaller number of meaningful PSUs than the number of households, the widely shared PSUs between households and across areas, and the proportional representation of recognized PSUs at each household, altogether reject the conclusion that pottery production was organized by each household in this part of Hongshan core zone.

5.2 Response to Research Question 2

RQ2: If each household did not make their own pottery, were pottery they consumed produced by a single producer or by multiple ones?

The short answer to this question is: multiple producers, instead of one single producer, made pottery that each household consumed. The term “producer”, as it was used here and elsewhere in this dissertation, indicates individual(s) who was/were most intensively involved in procuring raw materials and processing them for pottery production in their own ways. The term "producer" can refer to one person or to a group of individuals, and the term itself implies nothing about labor commitment (part-time or full-time), gender (male or female), skills, experience, and age. It is reasonable to believe, as was discussed in section 3.3, that there is a close correlation between a particular Hongshan producer and an identifiable compositional group (or PSU). This is because different producers often accumulated knowledge (such as raw materials procurement) at different levels, mastered different skills and techniques, maintained different technological and cultural traditions, required different approaches to produce vessels' texture, form, and size, and showed preferences for different recipes. Any or a combination of several such factors could have direct influence on pottery's chemical compositions. A PSU, in such a sense, is believed to indicate a pottery producer.

However, it must be realized that a PSU does not necessarily correspond strictly to one producer only, for the reason that a PSU is delineated by the similarity in pottery's geochemical compositions and it does not tell us exactly who made that pottery, where it was made, following what technical and cultural traditions (although we know that different PSUs must have stood for different technological and cultural characteristics). It is for this reason that we argue that, even though pottery represented by the 12 PSUs may not correspond strictly to 12 Hongshan producers, there is still a good chance that around 12 producers or producing groups are indicated for the 715 Hongshan sherds and 12 PSUs. Therefore, the number of identifiable PSUs strongly suggests that pottery consumed by each of the 16 Hongshan households was not produced by only one producer but by multiple (about 12) producers.

The hypothesis that one single producer produced pottery for all the 16 Hongshan households can also be rejected by examining the pattern shown in the 12 identifiable PSUs. For example, if there was one single Hongshan producer and if this producer stayed in one location and produced pottery for all the Hongshan residents nearby and elsewhere, then all Hongshan households would have shared the same PSUs as all pottery would be made from the same raw materials; besides, there would be fewer identifiable (even possibly one) PSUs as this single producer would continually make use of the materials most abundant and convenient to obtain, which produced stable and consistent PSUs. As a result, geochemical variations as revealed by pottery would have been only mild between households and across the three areas.

On the other hand, if there was one single Hongshan producer and if the producer travelled to different areas and made pottery for residents of visited Hongshan villages (although this possibility is very low considering the travel and other costs), households within different areas would have consumed different (groups of) PSUs as pottery would be made from raw materials immediately and only obtainable within each area. In this scenario, there would have been dramatic geochemical variations when pottery from two different areas was compared, which made different areas easily distinguishable. In addition, little or no intraregional pottery transfer would be noticed and

PSUs would not be shared across the geographical boundaries of the three areas.

However, the evidence we have seen in the 12 identifiable PSUs and their proportional representation at each household does not support either of the two above-mentioned assumptions. On the one hand, it is clear that not all households in the three areas shared the same PSUs. Neither is true that there were a very few PSUs (12 PSUs are definitely not "very few" compared to the 16 households that they characterized). In fact, each of the 16 households had pottery made from multiple PSUs (for instance, 14 out of the 16 households had access to 9 and 12 PSUs), and the proportional representation of identifiable PSUs varies from household to household. The geochemical variations between different areas are greater than expected and the differences in geochemical compositions of pottery consumed in different areas are even sharp enough to make the majority of pottery roughly distinguishable by their areas.

On the other hand, while PSUs were obviously shared across the three areas, different areas were noticed to have mainly concentrated on different groups of PSUs. For example, Erbuchi households relied heavily on PSUs 8 and 11, and Sanjia households on PSUs 1 and 2. Such a tendency for each area's households to rely on different combinations of PSUs implies that pottery production activities took place within each of the three areas. Some PSUs were more widely shared than others between different households and among different areas. Considering that pottery production occurred within each area, the shared PSUs might have just suggested intraregional pottery transfer (that is, pottery crossing the geographical boundaries of the three areas).

Concluding remarks: It seems easy to reject the hypothesis that there once existed one single Hongshan producer (and maybe one regional production center) who procured raw materials and made pottery for inhabitants of all Hongshan households identified by the upper Daling project. Pottery's geochemical compositions and the PSUs they characterized for each household and each area indicates pottery production activities organized within each residential area. More importantly, the 12 identifiable PSUs and the distribution patterns of these PSUs within different households and areas imply that there were multiple, rather than only one, Hongshan pottery producers.

Therefore, we can be confident to say that multiple producers in the three different areas produced the pottery we have investigated.

5.3 Response to Research Question 3

> *RQ3: If households tended to acquire all or most of their pottery from a single producer, did all households in a particular neighborhood rely largely on a single procurement source? Or were households utilizing different producers intermingled spatially within settlements?*

Toward the ending paragraph in response to Research Question 2, it was concluded that not every household made its pottery and neither did one single producer make pottery for inhabitants of all the 16 Hongshan households. The 12 identifiable PSUs and their proportional representations at each household could serve as very concrete evidence for the presence of multiple pottery producers/providers, rather than a single one. At all aspects, the hypothesis that one single producer had produced and provided pottery for households in the broad region across the three areas was not at all supported. Thus, Research Question 3 can be dismissed.

5.4 Response to Research Question 4

RQ4: If households tended to acquire pottery from multiple producers and sources (PSUs), did the proportions in which these PSUs were represented vary substantially from one household to the next? Or were the proportions of different PSUs quite similar across households within a settlement area?

The short answer to this question is: yes, all the 16 households procured pottery from multiple PSUs, and the proportional representation of PSUs does vary from household to household. However, it is also noticed that the proportional representation of PSUs looks more similar for households within the same area or the same neighborhood than those in different areas and neighborhoods.

When the spatial scale is zoomed in from several kilometers to a few hundred meters in both dimensions to make smaller groups of households (or neighborhoods) recognizable, even households from the same neighborhood almost always relied on diverse procurement sources rather than on a single procurement source (or the same producer) as their only (or main) pottery provider. What seemed also true is that households from the same or close neighborhoods often tended to procure and consume pottery more similarly (in terms of both the kinds and proportions of PSUs), although a very few households from two separate and more distant neighborhoods did occasionally consume very similar PSUs in similar proportions. All these findings suggest a very strong neighborhood-focused pottery distribution and consumption pattern but also some intra-neighborhood communication (though less frequent) in accessing and sharing pottery procurement sources.

The very strong similarity among households within the same neighborhood, which is usually delineated by a few closely spatially related households within a smaller spatial extent (one hundred meters or so in each direction), in consumption of procurement sources can be readily recognized when proportional representations of the twelve production source units (PSUs) were compared household by household and area by area.

Figure 5.1 makes such comparisons more easily noticed by displaying the proportions of PSUs in the form of bar graphs to represent the consumption of different procurement sources by each household.

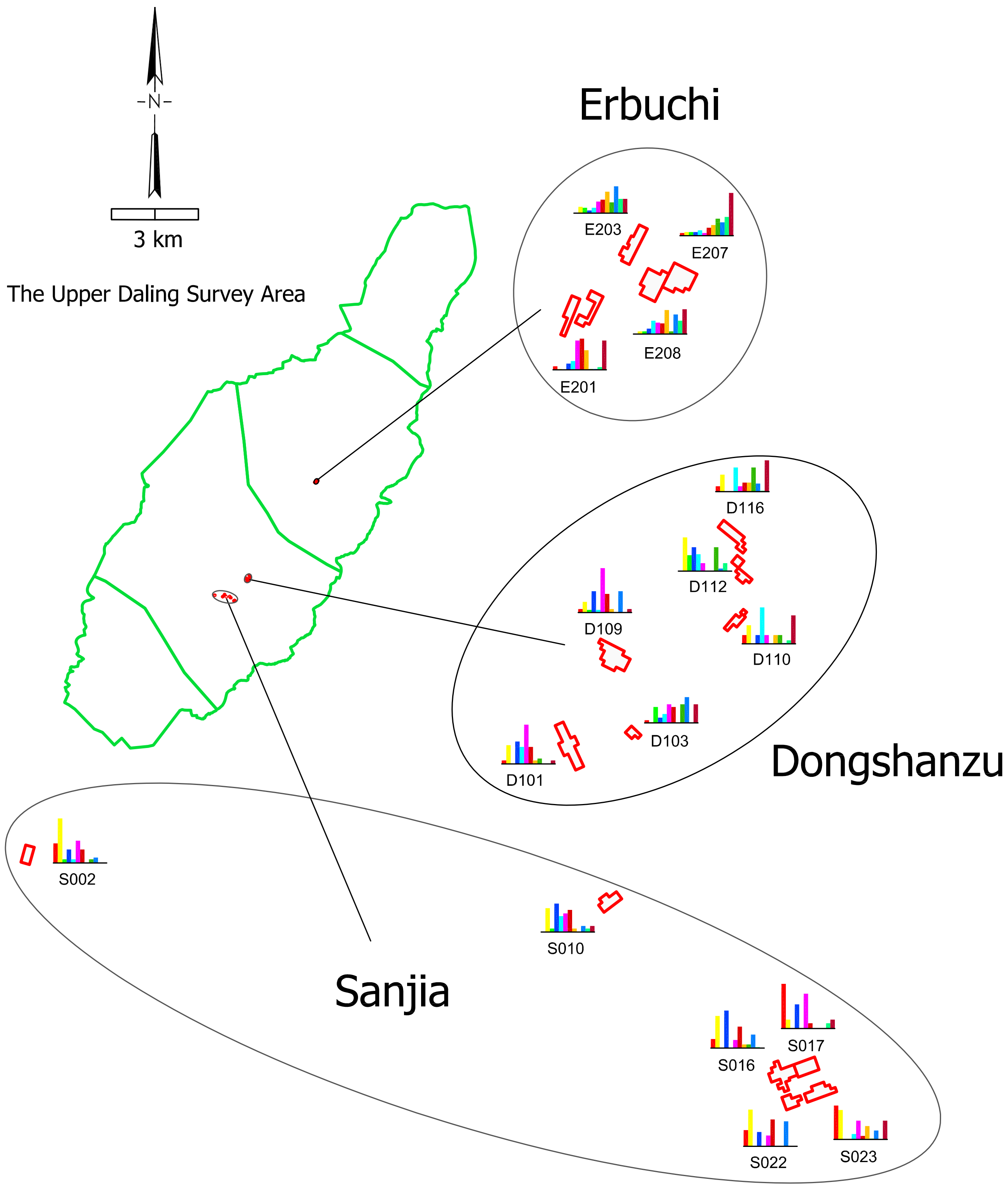

Figure 5.1: Pottery procurement patterns revealed by PSUs

In Figure 5.1, a clear and strong tendency is the changing focus on PSUs along the Sanjia-Dongshanzui-Erbuchi direction on a regional level; more specifically, the first six PSUs (PSU01 to PSU06) were mostly strongly emphasized by the six Sanjia households, which are located in the southern part of the survey area; while, on the other hand, PSU06 to PSU12 were more often noticed in much higher proportions for households in the Erbuchi area to the north of Dongshanzui and Sanjia areas. The Dongshanzui households were distributed in between Sanjia and Erbuchi areas yet much closer to Sanjia. Two of them (D101 and D109) demonstrated a pattern more similar to those in the Sanjia area while the other four (D103, D110, D112, and D116) behaved more like the four Erbuchi households did. Such a shift in reliance on different procurement sources among households corresponds well with the change in spatial distance between households, suggesting again a pattern of pottery making by multiple producers in different areas and a consumption focus on pottery made from local raw materials.

On an even smaller spatial scale, households very close to each other (within neighborhoods) often, although not always, demonstrated a higher degree of similarity in their consumption of pottery from different PSUs.

For example, in the neighborhood located in the southeast corner of the Sanjia area which consists of households S016, S017, S022, and S023, the two households on the west side (S016 and S022) both consumed higher proportions of pottery made from PSU02, PSU07, and PSU010, while S017 and S023 relied more heavily on PSU01, PSU06, and PSU12. The other two Sanjia households—S002 in the far western part and S010 in the middle part of the Sanjia area—very likely belonged to two other different neighborhoods. The household S002 consumed much pottery from PSU02 and less from PSU01, PSU04, PSU06, and PSU07, which is a consumption mode somewhat different from those seen in other Sanjia households. The household S010, however, has similar PSUs to the Dongshanzui household D101 than its neighbors in the Sanjia area, suggesting that its inhabitants' behaviors might have been more strongly influenced by those in the Dongshanzui area.

The two households (D101 and D109) towards the southwest of the Dongshanzui area and therefore closer to the Sanjia area demonstrated a greater similarity to the Sanjia households by consuming much pottery from PSU04, PSU06, and PSU07. By contrast, the three households (D110, D112, and D116) towards the northeast of the Dongshanzui area relied heavily on PSU05, PSU09, and PSU12.

Household E201 is located in the southwest corner of the Erbuchi area and therefore closer to the Dongshanzui area than the other three Erbuchi households. It relied very heavily on PSU06, PSU07, PSU08, and PSU12, the former two of which were noticed in high proportions especially among households on the northeast of the Dongshanzui area while the latter two occurred in higher proportions among all the three households (E203, E207, and E208) towards north end of the Erbuchi area.

A hierarchical cluster analysis (HCA) of households provides an even more straightforward quantification and visualization of the main observations discussed above. Figure 5.2 is a dendrogram that divides the 16 selected households into a small number of groups based on a measure of similarity in their consumption of different PSUs (see Table 3.1). The dendrogram structure helps identify four main groups when the rescaled distance between clusters generally lies between 15.2 and

17.8: (1) Group 1, which can be further divided into two smaller clusters—one consisting of three Sanjia households (S002, S016, and S022) and the other of one Sanjia (S010) and two Dongshanzui (D101 and D109) households; (2) Group 2, which consists of two Sanjia households (S017 and S023) only; (3) Group 3, which has the three households (D110, D112, and D116) towards north of the Dongshanzui area; and (4) Group 4, which includes all the four Erbuchi households (E201, E203, E207, and E208) and one Dongshanzui household (D103). The same distribution patterns can be noticed in a two-dimensional map of MDSCAL analysis as well (the results can be found in the University of Pittsburgh Comparative Archaeology Database <www.cadb.pitt.edu>).

To summarize, households were grouped in a slightly different way in the dendrogram than they were visually perceived on the map in Figure 5.1, but the general patterns remained quite similar in both Figure 5.1 and Figure 5.2: pottery production, distribution, and consumption was organized mainly on the neighborhood level, although intra-neighborhood and intra-regional exchange and/or trade occurred less frequently and less intensively. Consequently, Hongshan households in the three areas were actually using mixed pools of pottery producers, although their dependence on different PSUs was also certain. The spatial distance between households had a strong influence on pottery consumption behaviors of inhabitants living in those households. The chances are greater that two households closer to each other demonstrate high similarity in the kinds and proportions of PSUs that they had accessed and consumed than two households farther from each other.

Concluding remarks: The 12 identifiable PSUs definitely did not all occur, nor were they equally represented, at each of the 16 Hongshan households. In general, the contrast between households from different areas is greater than that noticed for households within the same area. Within the same area, not every household consumed PSUs in the same way, even though similarities are greater than differences among households.

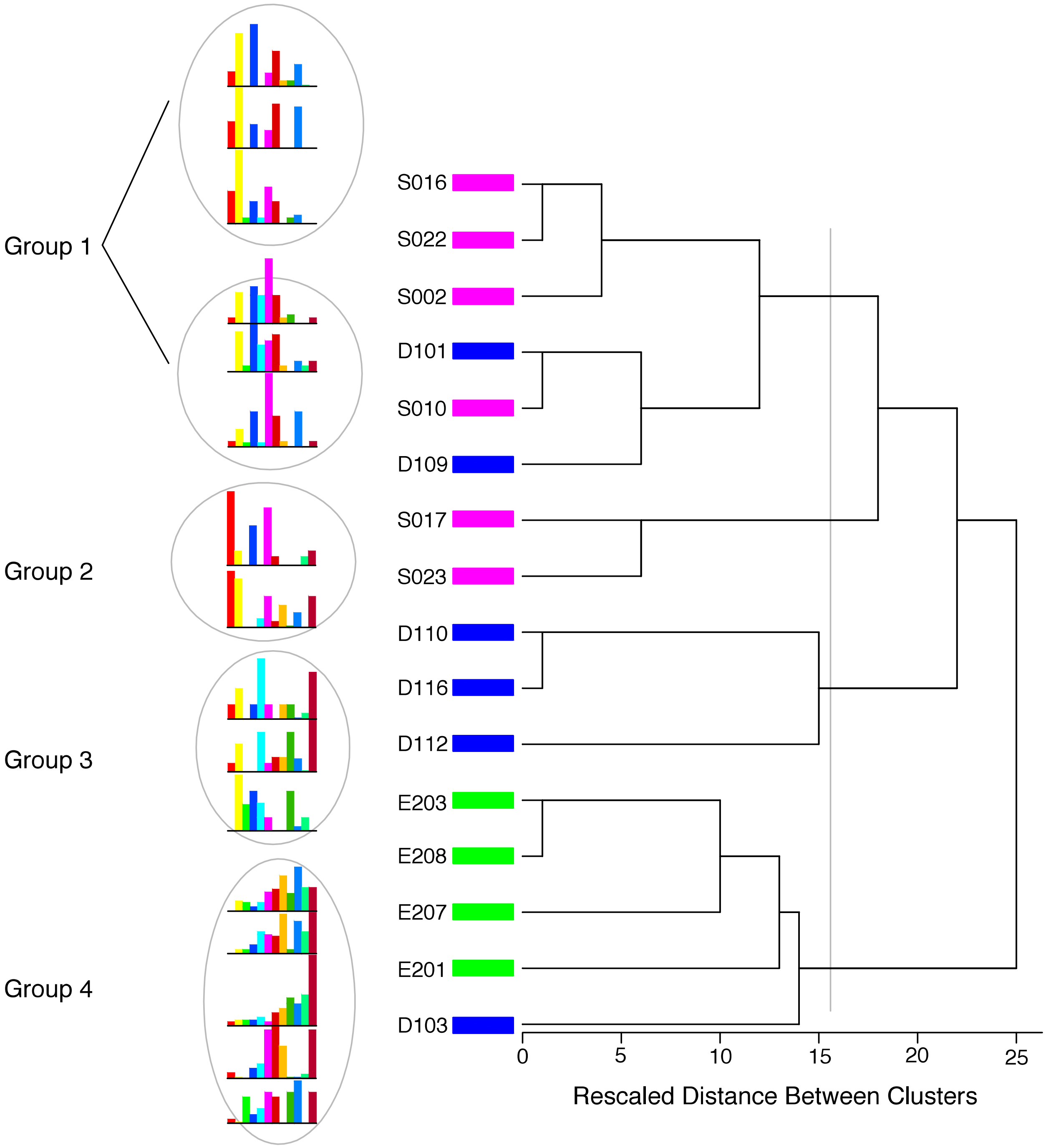

Figure 5.2: Households grouped on proportional representations of PSUs

5.5 Response to Research Question 5

RQ5: To what extent did utilitarian pottery distribution cross the boundaries between the supra-local communities or districts delineated in the regional settlement analysis?

The short answer to this question is: utilitarian pottery and non-utilitarian vessels were widely distributed across the geographical boundaries of the three areas studied, pertaining to two different districts, so clearly pottery crossed the spatial limits of supra-local Hongshan communities.

We came to this conclusion based on our observations on (1) the geochemical variations noticed for pottery consumed at each household and (2) the delineation of supra-local communities done by the upper Daling project. The upper Daling project delineated four supra-local Hongshan communities in the 200-km^2 survey area and two of them (District 2 and District 3) were fully included in the survey area with one including households in the Dongshanzui and Sanjia areas while the other included households in the Erbuchi area. As has been pointed out in our response to Research Questions 1 and 2, multiple producers within each of the three areas produced pottery for residents of local

Hongshan communities using locally procured raw materials. Therefore, the number of PSUs that each household within a Hongshan supra-local community had access to and the diversity and variability shown in groups of PSUs represented at different households enhances our understanding of pottery distribution networks (including the spatial extent of pottery distribution) among the three areas and the two Hongshan supra-local communities in particular.

From a geochemical perspective, if pottery produced within each of the three areas and/or in the two supra-local Hongshan communities did not cross their geographical boundaries, households within the same area or the same supra-local community would have consumed only the pottery made by local PSUs due to the exclusive use of local pottery raw materials, and not used pottery made by PSUs that characterize the other two areas or the other supra-local community. It means that different areas or supra-local communities would have always concentrated on different groups of PSUs, and barely possessed PSUs distributed outside of their spatial limits (other areas or supra-local communities). Such a pattern, when converted into the distribution of pottery's geochemical compositions, would result in a few (large) clusters that contained only the pottery from the same areas or the same supra-local community in each. On the dendrogram that is used as a classic way to graphically show the pottery's similarity/dissimilarity in their geochemical compositions, we would expect to see (1) pottery from the same area or the same supra-local community being highly compacted clustered together to form cluster(s) and (2) pottery from different areas or supra-local communities never being mixed in the same cluster.

However, as soon as the 12 compositional groups or PSUs were delineated on the dendrogram (see section 3.3 for details), it became obvious that the 16 investigated households representing three areas or two Hongshan supra-local communities had a strong geochemical complexity in their consumed pottery: (1) within each area, pottery consumed at neighboring households was sometimes but not always geochemically most alike. When pottery collected from the same area was compared by geochemical composition, many but not all households fell into the same cluster(s) to indicate the same PSUs. Sometimes, pottery (whether utilitarian or non-utilitarian) consumed at one household or area turned out to be geochemically more similar to that consumed at households in other areas. In each area, pottery produced by all 12 identifiable PSUs was noticed, suggesting that the imaginary "spatial separation between different areas witnessed by the focus on different groups of PSUs" did not exist; (2) while PSUs were widely shared between households and areas, no PSUs were restricted to one particular area or household. Even if we considered the Dongshanzui and Sanjia households as a single group of households representing one supra-local Hongshan community and the Erbuchi households as representing the other supra-local Hongshan community, such an observation would still be valid: inhabitants of Hongshan households anywhere in the three areas or in the two supra-local communities accessed pottery made from different PSUs without much difficulty. This can be seen as another indication that pottery distribution was not restricted to an area or a supra-local community; rather, it crossed the geographical boundaries of different areas and even the different supra-local communities.

Concluding remarks: Inhabitants of the 16 Hongshan households, no matter where they lived in the three areas or how they were divided by sociopolitical units, were able to possess pottery (whether non-utilitarian or utilitarian) made from almost all identifiable PSUs. We therefore strongly believe that the distribution network of Hongshan pottery was quite open. Both utilitarian and non-utilitarian pottery crossed the geographical boundaries of the three areas or those of the two supra-local Hongshan communities.

5.6 Response to Additional Research Question 1

> *How "specialized" was the production of non-utilitarian compared to utilitarian Hongshan pottery?*

The short answer to this question is: low-level specialization for both. We came to this conclusion based on our observations on the geochemical compositions of Hongshan utilitarian and non-utilitarian pottery vessels (mainly from a raw materials procurement point of view). We have already known that producers in each of the three areas made utilitarian and non-utilitarian pottery. The non-utilitarian vessels (Tongxingqi) have much larger size, more uniform shape and vessel form, and clearly finer texture and decorations than utilitarian Hongshan pottery do. If a high level of craft specialization were developed in Hongshan pottery production, we would be more likely to see some evidence of it on Tongxingqi vessels than on utilitarian pottery. For example, pottery raw materials procured from some particular loci would have been consistently used, and/or some specific processing techniques would have been developed or adopted, to ensure the good quality of final products of Tongxingqi vessels, which would generate a very high geochemical homogeneity among Tongxingqi vessels than for utilitarian pottery. If this actually occurred, we would have noticed that some PSUs were mainly or only noticed on Tongxingqi vessels and barely seen in utilitarian vessel; while utilitarian vessels, on the other hand, showed little or no preference to certain PSUs.

However, from the estimated proportional representations of Tongxingqi and utilitarian vessels in the 12 identifiable PSUs (proportions were estimated following the same procedures described in section 3.4), whose results are shown in Table 5.1 and Figure 5.3, we noticed that both non-utilitarian and utilitarian vessels were made from the same kinds of PSUs and no PSUs seems to be restricted to the production of Tongxingqi vessels or to the production of utilitarian (storage and serving) vessels. That is to say, no particular raw materials (as indicated by PSUs) were reserved for the production of non-utilitarian or utilitarian vessels across the three areas. From the geochemical perspective, compositions of non-utilitarian and utilitarian Hongshan vessels were always mixed together and not distinguishable from one another as two separate groups, suggesting that raw materials for making Tongxingqi vessels were no different from those used for making utilitarian vessels.

On the other hand, however, we have also noticed that, although non-utilitarian (Tongxingqi) vessels were not made from some intentionally chosen PSUs or raw materials, their geochemical compositions did look more consistent and less variable than those noticed on utilitarian vessels. This argument is strongly supported by Figure 5.4 that is a plot of two-dimensional scaling analysis of geochemical compositions of non-utilitarian and utilitarian pottery. The scatter plot was obtained through the construction of a similarity matrix with Euclidean distances of z-scored concentrations of the 11 elements on 212 Hongshan sherds whose vessel forms are identifiable.

Table 5.1: Proportions of (non-)utilitarian pottery made by different PSUs

Production Source Units (PSUs)	The sum of sherds in each PSU	The number of non-utilitarian vessel sherds in each PSU	Proportions and standard errors (%)	The number of serving vessel sherds in each PSU	Proportions and standard errors (%)	The number of storage vessel sherds in each PSU	Proportions and standard errors (%)
PSU01	46	12	9±8	0	0±0	1	2±3
PSU02	88	21	15±4	3	10±7	5	11±6
PSU03	23	7	5±2	3	10±7	3	6±5
PSU04	75	18	13±4	11	38±12	13	28±8
PSU05	50	8	6±3	4	14±8	1	2±3
PSU06	92	18	13±4	2	7±6	3	6±5
PSU07	69	11	8±3	2	7±6	4	9±5
PSU08	44	10	7±3	1	3±4	1	2±3
PSU09	40	6	4±2	1	3±4	3	6±5
PSU10	74	5	4±2	0	0±0	4	9±5
PSU11	39	8	6±3	2	7±6	6	13±6
PSU12	75	12	9±3	0	0±0	3	6±5
Total	715	136		29		47	

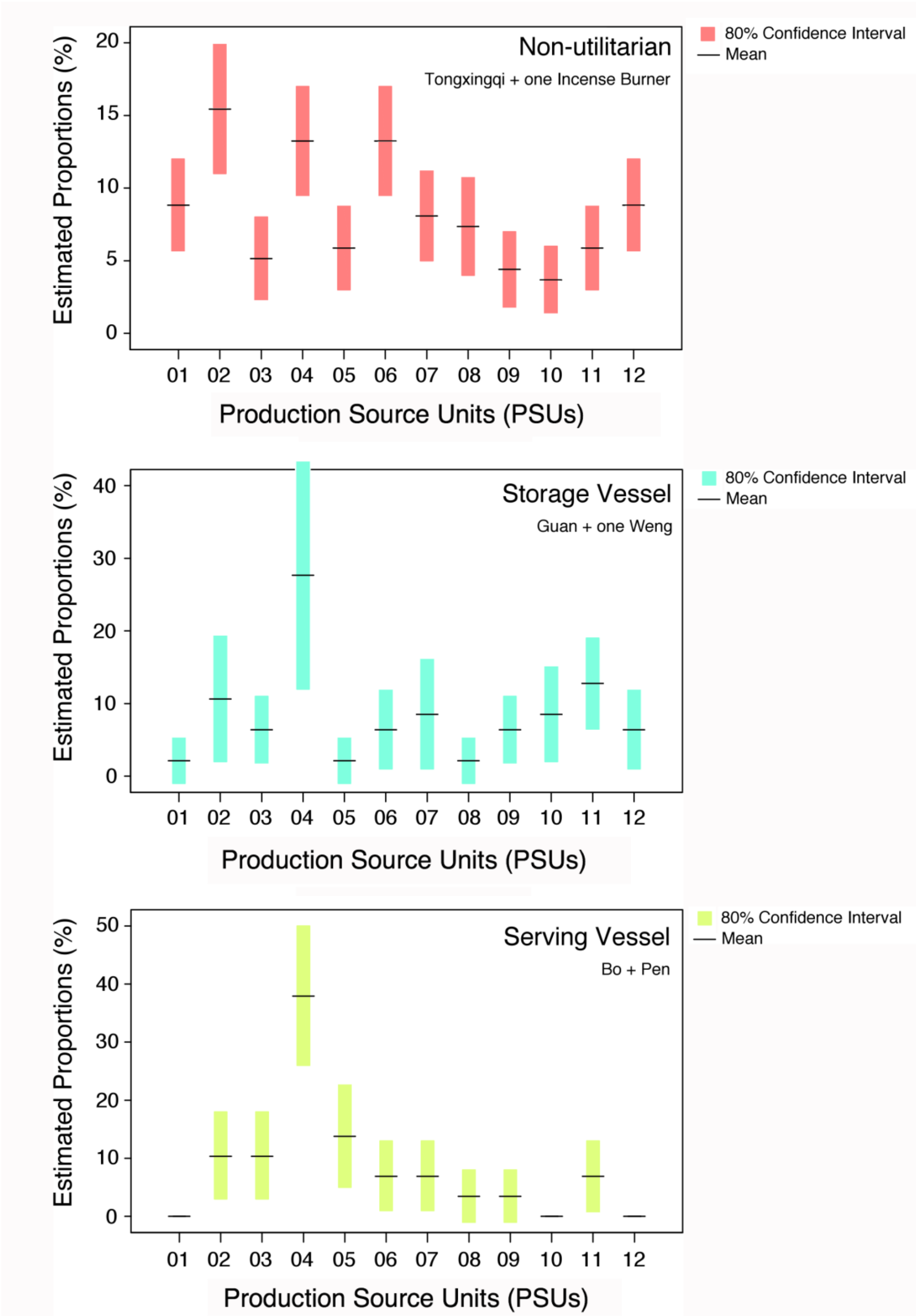

Figure 5.3: PSU distribution in non-utilitarian, storage, or serving vessels

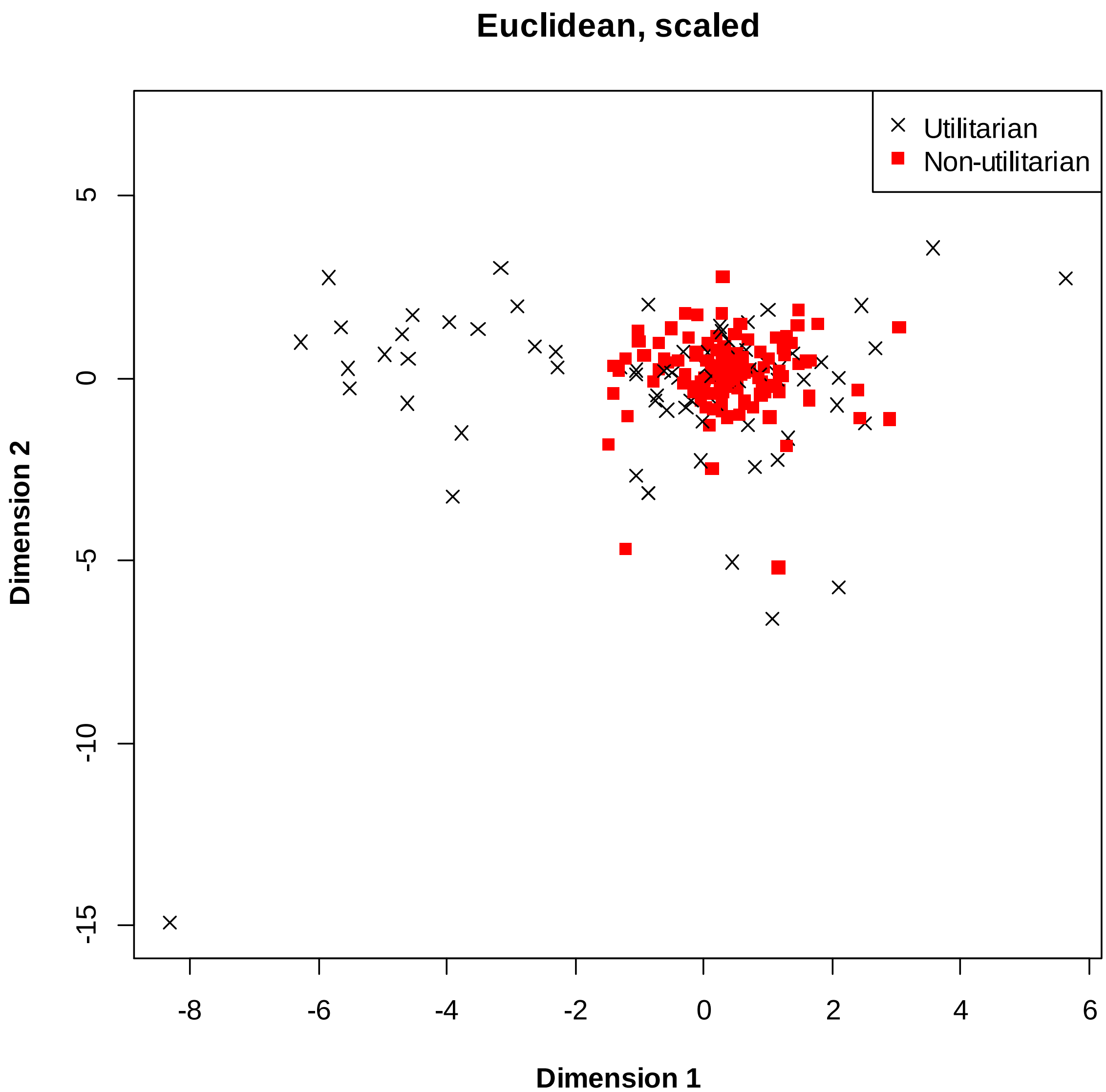

Figure 5.4: Geochemical variations in non-utilitarian and utilitarian vessels

It can be noticed in Figure 5.4 that the 136 non-utilitarian vessels (represented as red solid square) were closely clustered together while utilitarian pottery (including storage and serving vessels, represented as black x's) were geochemically more widely distributed. This distribution pattern of geochemical compositions suggests that Hongshan pottery producers must have established some degree of "standardization" for the production of non-utilitarian vessels, which may include (but is not limited to) similar standards for selecting soils and clays and similar procedures to get them ready for pottery production. Although Tongxingqi were more standardized in these ways than utilitarian vessels, the differences between the two classes of pottery are not overwhelming. A visible cluster of utilitarian vessels occurs in exactly the same part of the MDSCAL space where many Tongxingqi cluster. Both classes of pottery are also represented by a scatter of specimens lying out from this cluster, but such outliers are more abundant and more widely scattered for utilitarian vessels than for Tongxingqi. The degree of standardization in Tongxingqi production that is indicated is thus not dramatically greater than that seen for utilitarian vessels.

Concluding remarks: The Hongshan potters did not make non-utilitarian and utilitarian pottery with very different raw materials. However, Hongshan non-utilitarian vessels did show a greater geochemical homogeneity than utilitarian ones did, suggesting that a more restricted range of post-soil selection treatments might have been applied in the production of non-utilitarian vessels. Such a more careful labor investment in the production of non-utilitarian vessels suggests some degree of craft "specialization". However, considering the whole pattern of raw materials procurement, it was a very low level of specialization that falls far below the expectations that many scholars have proposed for Hongshan craft (pottery) production.

5.7 Response to Additional Research Question 2

> *What are the implications of pottery procurement for understanding economic or social status?*

The analyses we have carried out have revealed important information about pottery procurement by Hongshan households within and among different areas or different supra-local communities. It is clear that pottery distribution was spatially wide and crossed different areas and supra-local communities; that households anywhere in the three areas or in the two Hongshan supra-local communities acquired pottery made from multiple PSUs; that the proportions of PSUs represented at each household differ from one household to another; and that there were often one or two households standing out against others in the same neighborhood in terms of their pottery procurement (access to and proportions of different PSUs).

By looking at the way pottery made by different PSUs was procured and consumed at each Hongshan household, and by understanding the general pattern of pottery procurement pictured for different areas and especially in the two different Hongshan supra-local communities, we came to the conclusion that Hongshan households organized into the same neighborhood were often differentiated by their ability to access different PSUs and possess pottery made from them. As the access to and reliance on different PSUs reflects the ability, frequency, and intensity inhabitants of each Hongshan household maintained in communicating with their counterparts (pottery producers, for instance) within and outside of the same geographical region or the same sociopolitical unit, one naturally occurring thought would be that households with more diverse sources (PSUs) would suggest more intense interaction and communication with a greater number of different pottery producers. The motivation for a higher degree of interaction and communication on the part of some households is an interesting topic to explore, as it may closely relate to the sources of power that helped some Hongshan individuals or households to achieve higher status at least in this part of Hongshan core zone.

The upper Daling project has identified some (more precisely, 12) households with higher status from the 50 identified Hongshan households by carrying out multidimensional scaling analysis on ceramic assemblages recovered at these 50 households (R. Drennan, Personal Communication, June 14, 2015). Whether the higher status was wealth-related or prestige-related has remained unclear so far. Four variables were used to produce the clearest pattern, including: proportion of decorated sherds, proportion of slipped sherds, proportion of fine-paste sherds, and proportion of serving vessels. Five out of the 12 households with higher-status were included in the 16 selected Hongshan households, including three in the Sanjia area (S016, S017, and S022), one in the Dongshanzui area (D109), and one in the Erbuchi area (E201). Since we have already established the pottery procurement for these same five households as well as for eleven households without higher status, we would wonder if there would be any correlation between household status and pottery procurement patterns.

To approach such a goal, we need to find out: Did higher-status households acquire pottery and pottery procurement sources in a whole different way than households with lower status did? Or did they all behave in the same or similar ways? This question can be answered by an examination and comparison of the proportional representations of identifiable PSUs noticed for those higher-status and lower-status households.

Figure 5.5 places the proportional representations of PSUs at the five higher-status households (S016, S017, S022; D109; E201) on the left and those at the other eleven households with lower status (S002, S010, S023; D101, D103, D110, D112, D116; E203, E207, E208) on the right, both in an order of spatial progression from the southern to the middle part of the survey region if examined from the top to the bottom. One observation that can be made instantly on Figure 5.5 is that higher-status households unanimously strongly concentrated on a few (usually three or four) PSUs, which as a whole could account for about 70% to 80% or more of their pottery; and that they consumed very little pottery made from other PSUs. In contrast, households with lower status relied on more (usually five or more, and very rarely less than four) PSUs in a general way. For households with lower status, proportions of all more strongly represented PSUs are at about the same levels. PSUs with exceptionally high proportions were either rarely noticed or occurred in very limited cases.

For example, higher-status Sanjia households S016, S017 and S022 consumed high proportions of somewhat different combinations of PSUs: S016 (67% of their pottery was made from PSU02, PSU04, and PSU07); S017 (77% of its pottery was made from PSU01, PSU04, and PSU10; and S022 (66% of its pottery was made from PSU02, PSU07, and PSU10). The Dongshanzui higher-status household D109 concentrated strongly on PSU04, PSU06, PSU07, and PSU10, which accounts for 79% of its pottery compared to 17–59% for the same four PSUs in the other five Dongshanzui households with lower status. The Erbuchi household E201 consumed highly on PSU06, PSU07, PSU08, and PSU12, which accounts for 82% of its pottery.

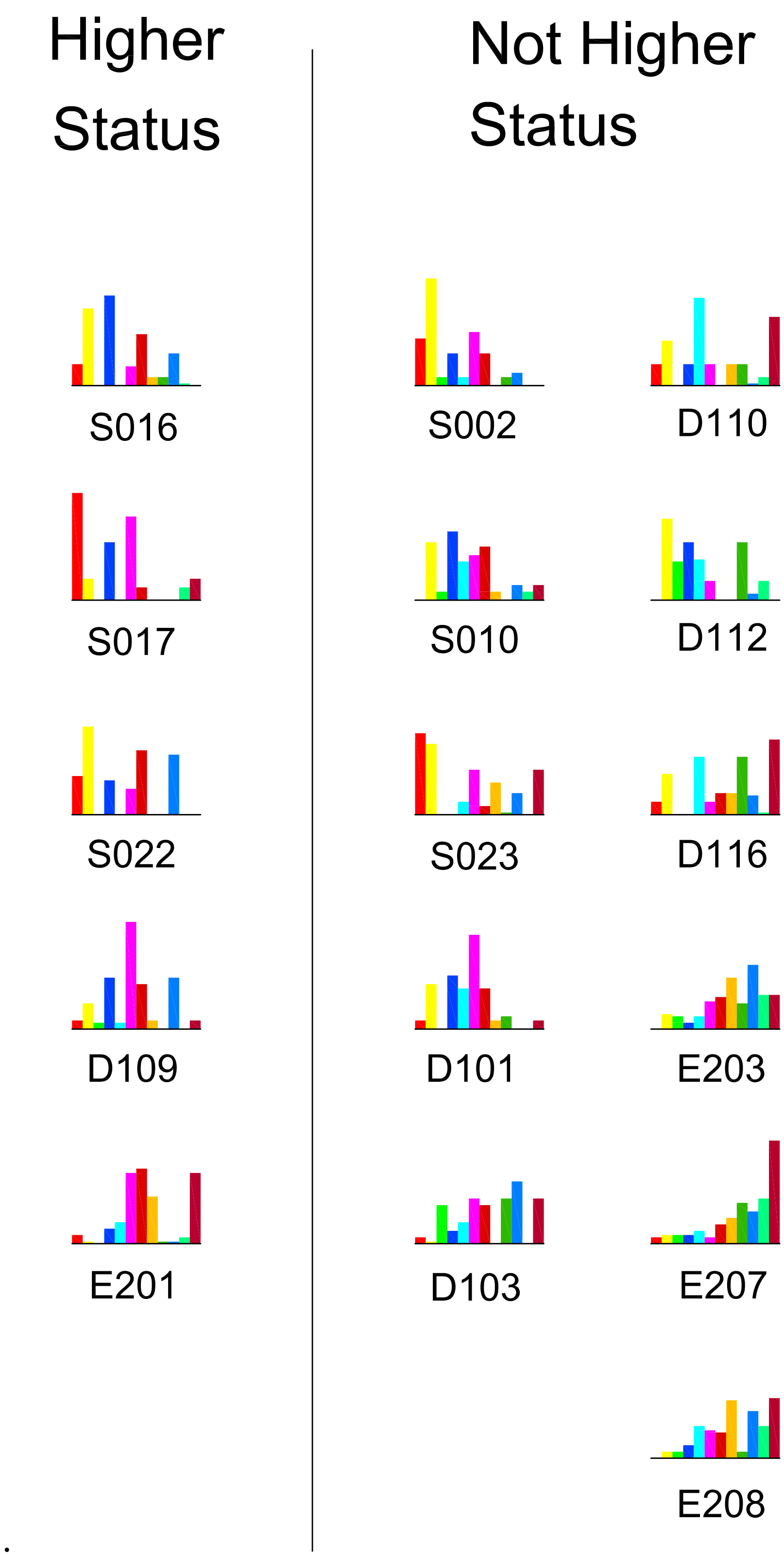

Figure 5.5: Correlation between pottery procurement and household status

In contrast, the other three Sanjia households (S002, S010, S023) with lower status consumed highly on at least five different PSUs: S002 (85% of its pottery was made from PSU01, PSU02, PSU04, PSU06, and PSU07); S010 (92% of its pottery was made from PSU02, PSU04, PSU05, PSU06, and PSU07); and S023 (85% of its pottery were made from PSU01, PSU02, PSU06, PSU08, and PSU12). Of the five Dongshanzui households with lower status, three (D101, D103, D112) consumed highly on five PSUs, while the other two (D110 and D116) concentrated on three (PSU02, PSU05, PSU12) and four (PSU02, PSU05, PSU09, PSU12) PSUs, respectively. The three Erbuchi households with lower status (E203, E207, E208) all consumed reasonably high proportions of four or five PSUs. Thus, it seems promising to argue that higher-status and lower-status Hongshan households consumed PSUs quite differently, with the former making more intensive use of only a few PSUs while the latter making *extensive* use of PSUs as many as possible.

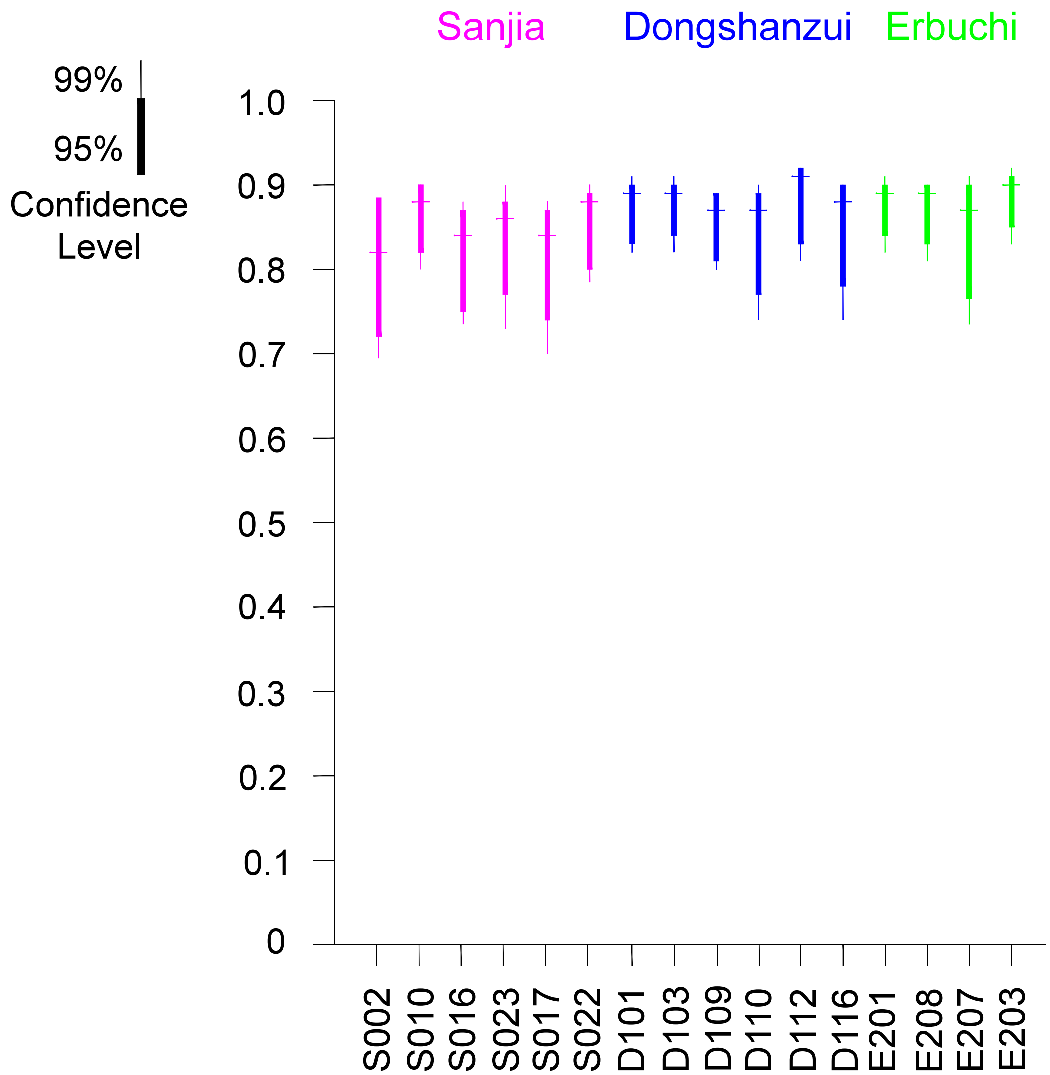

Figure 5.6: Simpson's Diversity Index for the 16 Hongshan households

Figure 5.6 shows the calculated mean and error range of Simpson's index of diversity for each of the 16 Hongshan households. The Simpson's index of diversity in this case is a measure of diversity in pottery procurement sources and it takes into account both the kinds and relative abundance of PSUs noticed for each household. In general, all households have a pretty high diversity (the D value lies between 0.82 and 0.91), which is simply a reflection of the fact that a good many PSUs are represented at each of the 16 households. Given the small sample size and large error ranges in Figure 5.6, differences between households do not have much statistical significance. However, there are some patterns worth mentioning. Most of the households that are not higher status have diversity values either noticeably higher or lower than values noticed for the higher status households, which could be an indication for a relatively consistent degree of diversity in pottery procurement for higher status households.

Further examination of Figure 5.5 reveals detail that is behind this pattern. As discussed earlier, higher status households usually have high proportions of three or sometimes four PSUs, which reflects a pattern in which a consistent three or four PSUs were strongly favored by these higher status households and contributed to 70-80% of the household's pottery while other PSUs were represented only much more weakly. It is not always the same three or four PSUs, but there is always a strong representation of three or four PSUs in higher status households. Often (although not always) those three or four strongly represented PSUs occur in quite similar proportions; only in the case of household D109 does a single PSU stand out as clearly the most strongly represented. As for the households without indications of higher status, on the other hand, they very often have a larger number of relatively high proportions and/or a less clear separation between a few high proportions and the rest that are lower. This usually produces a higher PSU diversity index for lower status households, although there are exceptions, such as household D110 with a pattern (and a diversity index) very like that of higher status households, and households S002 and E207 with a single strongly dominant PSU that produces a lower diversity score.

Concluding remarks: The subtle but consistently patterned distinction between higher and lower status households in regard to pottery procurement could be a clue to different ways in which higher and lower status households tend to participate in economic networks. Higher status households, like lower status ones, seem to procure pottery from many PSUs, but they consistently seem to have three or four especially strong connections. This might reflect the higher status households' successful balance between breadth and depth of social and economic network ties to other households (in this case to pottery producing households). A modest number of network links seem well developed (and similarly well developed), and the distinction between these and the weaker links to a larger number of PSUs is clearer for higher status households.

5.8 Summary

Pottery production in Hongshan core zone of northeastern China seems quite similar to that seen at early to middle Neolithic sites in other parts of China. Pottery-making was organized in different areas and probably carried out near residential places, using raw materials that can be easily procured, to serve the needs of different local populations. Pottery-making techniques were quite simple and did not involve much highly specialized activities (such as very complicated shaping and decorating work). Utilitarian vessels were made mainly to serve the needs of everyday life and were far less variable in form; by contrast, non-utilitarian vessels were clearly produced with more labor investment and probably at some low level of specialization, even though they were no different from utilitarian ones in terms of raw materials sources. Such information altogether indicated an ordinary Neolithic village economy for Hongshan core zone communities. The same conclusion should also hold true for Hongshan societies in the periphery.

On the other hand, although Hongshan households in each residential zone showed a focus on more *local* sources of pottery, pottery made from different producers was indeed widely distributed across a wide landscape and shared between different neighborhoods, areas, and political entities. This led us to believe that people from a few nearby districts (a few km apart from each other, like the spatial distances between the Sanjia, Dongshanzui, and Erbuchi areas) participated in the same pottery distribution networks. Such interactions almost certainly did not involve transferring pottery (utilitarian or non-utilitarian) hundreds of km from one end of the Hongshan zone to the other end (after all, no pottery of non-local origin was identified among the 715 Hongshan sherds analyzed for this study). Pottery exchange involving only a relatively small set of neighboring districts can, nonetheless, create a chain of interaction that indirectly connects a population across a large area like that of the Hongshan culture area and facilitates the kind of cultural sharing of styles and other behaviors that amount to an archaeological culture (the Hongshan culture).

The varying kinds and proportions of pottery consumed at the 16 Hongshan households disclosed even more interesting aspects of economic ties, household variability, and status differentiation in this part of the Hongshan core zone than was expected. In each area, few households stood out against others for their higher status. These households all seemed to have established a much stronger economic tie with fewer pottery producers than their neighbors of commoner households did. In broad terms, it seems not the ability to access as many PSUs as possible that helped these households attain higher status, but instead stronger ties with fewer PSUs. However, considering that higher-status households did not have exclusive access to certain pottery producers and that they did not rely primarily on just one or two producers, control over production and distribution of pottery does not seem to be indicated and could thus not have been a principal strategy employed by Hongshan households to achieve higher status and whatever degree of power over others they might have enjoyed.

APPENDIX. ELECTRONIC ACCESS TO DATASETS AND IMAGES

The geochemical and mineralogical datasets collected by this research are available online in the University of Pittsburgh Comparative Archaeology Database <www.cadb.pitt.edu>. The intent is that these two datasets can be used for comparative purposes or further data exploratory analysis by researchers who are interested in sourcing pottery geochemically or mineralogically using the same analytical methods and instruments (the Niton handheld x-ray fluorescence analyzer or the semi-quantitative powdery x-ray diffraction analysis with the Rietveld method).

The two datasets are available as tabular data in .xls and comma-delimited ASCII text, which document in detail the elements (or mineral phases) and their concentrations (or percentages), as well as the archaeological contexts for each corresponding sherd that generated the geochemical (or mineralogical) composition. Results of some trial analyses (hierarchical cluster analysis and multidimensional scaling analysis) on the two datasets, produced by R programming language, are presented as PDF files.

BIBLIOGRAPHY

CHEN Guoqing 陳國慶

2003 Qianxi Hongshan Wenhua Tongxingqi 淺析紅山文化筒形器 (Preliminary Discussion on Hongshan Bottomless Cylindrical Jars). *Beifang Wenwu 北方文物 (Northern Cultural Relics)* 2003(4):9-14.

CHEN Guoqing 陳國慶, and ZHANG Quanchao 張全超

2008 Qianxi Liaoxi Diqu Shiqian Shidai De Taoyao 淺析遼西地區史前時代的陶窯 (Preliminary Analysis of Prehistoric Pottery Kilns Found in Western Liaoning). *Neimenggu Wenwu Kaogu 內蒙古文物考古 (Inner Mongolian Cultural Relics and Archaeology)* 2008(1):61-65.

CHEN Xingcan 陳星燦

1990 Hongshan Wenhua Caitao Tongxingqi Shi Taogu Tuikao 紅山文化彩陶筒形器是陶鼓推考 (Was Hongshan Painted Pottery Cylinders Used as Drums?). *Beifang Wenwu 北方文物 (Northern Cultural Relics)* 1990(1):26-29.

Chifeng International Collaborative Archaeological Research Project

2011 *Settlement Patterns in the Chifeng Region*. Pittsburgh, PA: Center for Comparative Archaeology, University of Pittsburgh.

Drennan, Robert D., LU Xueming 吕學明, and Christian E. Peterson

In press Niuheliang and Its Place in Hongshan Society. *Antiquity*.

Drennan, Robert D., and Christian E. Peterson

2006 Patterned Variation in Prehistoric Chiefdoms. *Proceedings of the National Academy of Sciences* 103(11):3960-3967.

Fultz, Brent, and James M. Howe

2013 *Transmission Electron Microscopy and Diffractometry of Materials*. Fourth ed. Heidelberg: Springer Berlin Heidelberg.

Goren, Yuval, Hans Mommsen, and Jörg Klinger

2011 Non-Destructive Provenance Study of Cuneiform Tablets Using Portable X-Ray Fluorescence (pXRF). *Journal of Archaeological Science* 38(3):684-696.

GUO Dashun 郭大順

1995 Hongshan and Related Cultures. In *The Archaeology of Northeast China: Beyond the Great Wall*, Sarah M. Nelson (ed.), pp. 21-64. London and New York: Routledge.

2007 Liaohe Liuyu Wenming Qiyuan Yanjiu De Huigu Yu Qianzhan 遼河流域文明起源研究的回顧與前瞻 (Retrospection and Prospect of Research on the Origin of Civilization in the Liao River valley). *Liaoning Shifan Daxue Xuebao 遼寧師範大學學報 (Journal of Liaoning Normal University)* 2007(1):113-116.

2008 Dongbei Wenhua Yu Hongshan Wenming 東北文化與紅山文明 (Ancient Cultures in Northeastern China and Hongshan Civilization). *Dongbei Shidi 東北史地 (Northeastern History and Geography)* 2008(5):50-56.

GUO Zhizhong 郭志忠

2009 Hongshan Wenhua Yanjiu Licheng De Huigu Yu Zhanwang 紅山文化研究歷程的回顧與展望 (Review of History of Research on Hongshan Culture and Prospect of Future Research). *Neimenggu Wenwu Kaogu 內蒙古文物考古 (Inner Mongolian Cultural Relics and Archaeology)* 2009(1):45-53.

Hall, Gwendy E.M.

2012 Evaluation of the Performance of Portable XRF in the Mineral Exploration and Mining Industry. Geoanalysis 2012 (The 8th International Conference on the Analysis of Geological and Environmental Materials), Buzios, Rio de janeiro, Brazil.

HUANG Jiwu 黃繼武, and LI Zhou 李周 (eds.)

2012 *Duojing Cailiao X Shexian Yanshe: Shiyan Yuanli, Fangfa, Yu Yingyong 多晶材料 x 射線衍射:實驗原理、方法與應用 (X-Ray Diffraction of Polycrystalline Materials: Principles, Techniques, and Applications).* Beijing 北京: Metallurgical Industry Press 冶金工业出版社.

LI Baoping, ZHAO Jianxin, Kenneth D. Collerson, and Alan Greig

2003 Application of ICP-MS Trace Element Analysis in Study of Ancient Chinese Ceramics. *Chinese Science Bulletin* 48(12):1219-1224.

LI Gongdu 李恭篤

1977 Liaoning Aohanqi Xiaoheyan Sanzhong Yuanshi Wenhua De Faxian 遼寧敖漢旗小河沿三種原始文化的發現 (Remains of Primitive Culture at Hsiao-Ho-Yen in Aohan Banner, Liaoning Province). *Wenwu 文物 (Cultural Relics)* 1977(12):1-22.

LI Gongdu 李恭篤, and GAO Meixuan 高美璇

1987 Neimenggu Aohanqi Silengshan Hongshan Wenhua Yaozhi 內蒙古敖漢旗四棱山紅山文化窯址 (Hongshan Pottery Kilns Excavated at Silengshan in Aohan Banner, Inner Mongolia). *Shiqian Yanjiu 史前研究 (Prehistory)* 1987(4):4-18.

Liaoning Province Institute of Archaeology and Cultural Relics 遼寧省文物考古研究所, and School of History at Renmin University of China 中國人民大學歷史學院

2015 2014 Nian Niuheliang Yizhi Xitongxing Quyu Kaogu Diaocha Yanjiu 2014 年牛河梁遺址系統性區域考古調查研究. *Huaxia Kaogu 華夏考古 (Huaxia Archaeology)* 2015(3):3-8.

LU Xueming 吕學明, Christian E. Peterson, Robert D. Drennan, and ZHU Da 朱達

2010 Liaoning Dalinghe Shangyou Liuyu Kaogu Diaocha Jianbao 遼寧大凌河上游流域考古調查簡報 (Preliminary Report on the Archaeological Survey to the Upper Reach of Daling River, Liaoning). *Kaogu 考古 (Archaeology)* 2010(5):24-35.

LU Xueming 吕學明, and ZHU Da 朱達

2008 *Chongxian Nushen: Niuheliang Yizhi 重現女神: 牛河梁 (Rediscovery of the Goddess: Niuheliang Site)*. Tianjin 天津: Tianjin Guji Chubanshe 天津古籍出版社.

Nelson, Sarah M.

2003 Introduction. In *The Archaeology of Northeast China: Beyond the Great Wall*, Sarah M. Nelson (ed.), pp. 1-21. London and New York: Routledge.

Orton, Clive, and Michael Hughes

2013 *Pottery in Archaeology*. New York: Cambridge University Press.

Peacock, David P. S.

1970 The Scientific Analysis of Ancient Ceramics: A Review. *World Archaeology* 1(3):375-389.

PENG Bangben 彭邦本

1990 Niuheliang Yizhi Yu Wenming Qiyuan De Zhu Yinsu 牛河梁遺址與文明起源的諸因素 (Niuheliang Archaeological Site and Driving Forces for Early Civilizations). *Chifeng Xueyuan Xuebao (Hanwen Zhexue Shehui Kexueban) 赤峰學院學報(華文哲學社會科學版) (Journal of Chifeng College, Philosophy and Social Science)* 1990(3):11-18.

Peterson, Christian E.

2006 "Crafting" Hongshan Communities? Household Archaeology in the Chifeng Region of Eastern Inner Mongolia, PRC. Ph.D. Dissertation, Department of Anthropology, University of Pittsburgh, Pittsburgh, PA.

Peterson, Christian E., and LU Xueming 吕學明

2013 Understanding Hongshan Period Social Dynamics. In *A Companion to Chinese Archaeology*, Anne P. Underhill (ed.), pp. 55-80. Boston, MA: Wiley-Blackwell.

Peterson, Christian E., LU Xueming 吕學明, Robert D. Drennan, and ZHU Da 朱達

2010 Hongshan Chiefly Communities in Neolithic Northeastern China. *Proceedings of the National Academy of Sciences* 107(13):5756-5761.

2014 *Hongshan Regional Organization in the Upper Daling River Valley 大凌河上游流域紅山文化區域性社會組織*. Pittsburgh 匹茲堡; Shenyang 瀋陽: University of Pittsburgh Center for Comparative Archaeology 匹茲堡大學比較考古學中心; Liaoning Province Institute of Archaeology and Cultural Relics 遼寧省文物考古研究所.

Rice, Prudence M.

1987 *Pottery Analysis: A Source Book*. Chicago, IL: University of Chicago Press.

Steponaitis, Vincas P., M. James Blackman, and Hector Neff

1996 Large-Scale Patterns in the Chemical Composition of Mississippian Pottery. *American Antiquity* 61(3):555-572.

SU Bingqi 蘇秉琦

1986 Liaoxi Diqu De Guwenhua, Gucheng, Guguo 遼西地區的古文化古城古國 (Ancient Cultures, Ancient Cities, and Ancient States in Western Liao Region). *Wenwu 文物 (Cultural Relics)* 1986(8):41-44.

1988 Zhonghua Wenming De Xinshuguang 中華文明的新曙光 (New Light on the Chinese Civilization). *Dongnan Wenhua 東南文化 (Southeast Culture)* 1988(5):1-7.

SUN Shoudao 孫守道, and GUO Dashun 郭大順

1984 Lun Liaohe Liuyu De Yuanshi Wenming Yu Longde Qiyuan 論遼河流域的原始文明與龍的起源 (Primitive Civilization in the Liao River Valley and the Origin of Dragon). *Wenwu 文物 (Cultural Relics)* 1984(6):11-20.

TENG Haijian 騰海建

2009 Hongshan Wenhua De Shengchan Jishu Zhuangkuang Ji Shengchanli Shuiping Shulun 紅山文化的生產技術狀況及生產力水平初論 (Review of Hongshan Culture Production Technology Status and Productivity Levels). *Chifeng Xueyuan Xuebao (Hanwen Zhexue Shehui Kexueban) 赤峰學院學報(華文哲學社會科學版) (Journal of Chifeng College, Philosophy and Social Science)* 30(4):3-8.

Tite, Michael S.

1999 Pottery Produciton, Distribution and Consumption: The Contribution of the Physical Sciences. *Journal of Archaeological Method and Theory* 6(3):181-233.

2008 Ceramic Production, Provenance and Use: A Review. *Archaeometry* 50(2):216-231.

Underhill, Anne P.

1996 Craft Production and Social Evolution During the Longshan Period of Northern China. In *Craft Specialization and Social Evolution: In Memory of V. Gordon Childe*, Bernard Wailes (ed.), pp. 133-150. Philadelphia, PA: The University of Pennsylvania Museum of Archaeology and Anthropology.

WANG Huide 王惠德

1989 Lun Hongshan Wenhua Daibiao De Zhongguo Gudai Wenming 論紅山文化代表的中國古代文明 (Discussion on Hongshan Culture and Ancient Chinese Civilizations). *Chifeng Xueyuan Xuebao (Hanwen Zhexue Shehui Kexueban) 赤峰學院學報(華文哲學社會科學版) (Journal of Chifeng College, Philosophy and Social Science)* 1989(2):48-55.

Waseda, Yoshio, Eiichiro Matsubara, and Kozo Shinoda

2011 *X-Ray Diffraction Crystallography: Introduction, Examples, and Solved Problems*. Heidelberg: Springer-Verlag Berlin Heidelberg.

Will, Georg

2006 *Powder Diffraction: The Rietveld Method and the Two Stage Method to Determine and Refine Crystal Structures from Powder Diffraction Data*. Berlin Heidelberg: Springer-Verlag Berlin Heidelberg.

WU Guangju 乌广聚

1991 *Kaerqin Zuoyi Menguzu Zhizhixian Dimingzhi 喀喇沁左翼蒙古族自治县地名志 (Toponymy Study of Harqin Left Wing Mongol Autonomous County)*. Shenyang 沈阳: Liaoning Nationalities Press 辽宁民族出版社.

XU Zifeng 徐子峰

2004 Hongshan Wenhua Jingji Xingtai Chutan 紅山文化經濟形態初探 (Preliminary Discussion on Hongshan Economy). *Chifeng Xueyuan Xuebao (Hanwen Zhexue Shehui Kexueban) 赤峰學院學報(華文哲學社會科學版) (Journal of Chifeng College, Philosophy and Social Science)* 25(2):5-6.

Young, R. A. (ed.)

1993 *The Rietveld Method*. Oxford: IUCr/Oxford University Press.

ZHU Yanping 朱延平

2007 Hongshan Wenhua Caitao Wenyang Tanyuan 紅山文化彩陶紋樣探源 (Seeking the Roots of Designs on Painted Hongshan Pottery). *Bianjiang Kaogu Yanjiu 邊疆考古研究 (Research of China's Frontier Archaeology)* 2007(01):78-87.

Zurfluh, Florian J., Beda A. Hofmann, Edwin Gnos, and Urs Eggenberger
2011 Evaluation of the Utility of Handheld XRF in Meteoritics. *X-ray Spectrometry* 40(6):449-463.